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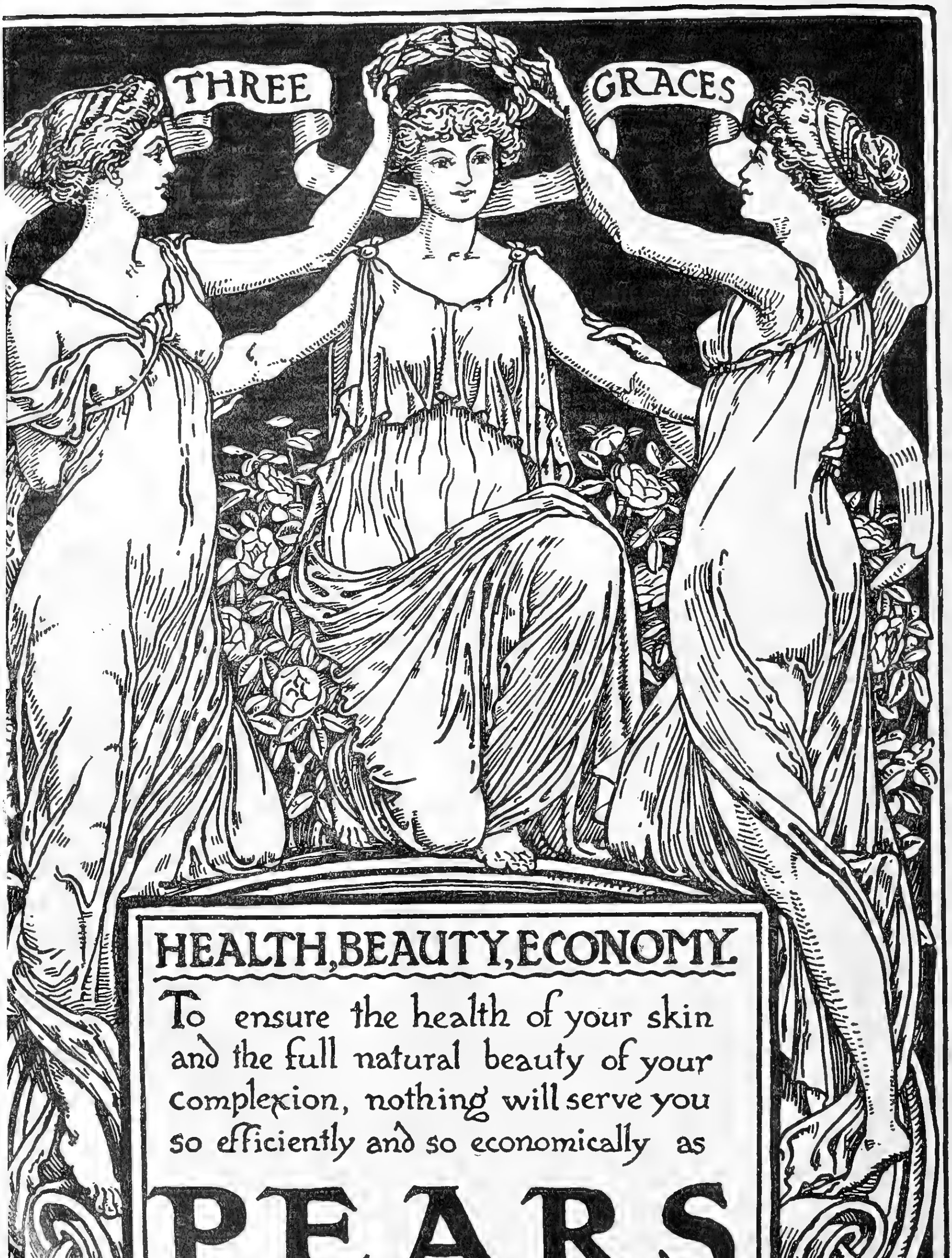
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THE
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JANUARY-FEBRUARY, 1910

THE NITRATE DEPOSITS OF CHILE

R. A. F. PENROSE, Jr.

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LOCATION OF THE NITRATE REGIONS

The nitrate deposits of Chile are in the northern part of that country, in the region lying between about 19° and 26° south latitude, and mostly in the provinces of Tarapacá and Antofagasta. Some more or less isolated deposits have been found both north and south of these limits, but, as yet, have not proved of very great extent.[1] The Tarapacá region has been worked for a longer time, and at present supplies more nitrate than the Antofagasta region, but the latter is an important producer and has great future possibilities.

[1] Many changes have occurred in the last thirty years in the boundaries separating Chile, Peru, and Bolivia; and even provinces which bear the same names now as they did then may have different boundaries, so that different accounts of this region written at different times necessarily conflict in statements of boundaries and names. The data in the present paper are based on the boundaries of states and provinces as they now exist.

The nitrate deposits are found at intervals in an arid region known as the pampa, which runs north and south in a long narrow belt for almost five hundred miles between the Andes on the east and the Coast Range on the west, and from a few miles to over one hundred miles inland.

During the year 1907 the writer visited some of the nitrate regions of northern Chile, and the present paper embodies his investigations there. The remarks apply mostly to the Tarapacá region, unless otherwise stated, as that was the only part of the field carefully studied. There is, however, much similarity in many of the features of the nitrate deposits in both Tarapacá and Antofagasta, though in some respects they differ considerably.

HISTORY OF THE NITRATE MINING INDUSTRY

The nitrate deposits of Chile have probably been known from very ancient times, but the extensive mining and utilization of them is a comparatively modern industry. During the wars for independence which the countries on the west coast of South America waged against Spain in the early part of the nineteenth century, the nitrates are said to have been utilized to make niter for gunpowder. The first operations to handle nitrate on any considerable scale, however, are said to have been started by a Frenchman named Hector Bacque, at La Noria, in Tarapacá, about 1826.[1] This enterprise was followed by a number of others, and in the next fifty years, many similar operations were started by Europeans, Americans, and Chileans.

The early enterprises were all in what is now the province of Tarapacá, a region which at that time belonged to Peru, and which was supposed to be the only part of this coast that contained nitrate; but as the industry grew and began to attract more general notice, search was made for nitrate elsewhere. The result was the discovery of deposits in the province of Antofagasta, lying south of Peruvian territory, and active mining operations were soon started there. At this time, the northern part of what is now Antofagasta belonged to Bolivia and the southern part to Chile. The Chilean government, recognizing the importance of the new discoveries, sent out a commission to investigate the occurrence of nitrate in Chilean

[1] G. F. Scott Elliot, *Chile*, p. 259.

territory. The report of this commission was published by the government and was printed in English, in London, in 1878. It shows that at that time active mining was going on both in Bolivia and in the adjoining Chilean territory. In both regions, Chilean capital and Chilean labor were employed to a large extent.

As the industry grew, Bolivia imposed an export tax on the nitrate shipped from her territory, which Chile considered inconsistent with certain treaty rights existing between the two countries. Chile protested against the injury done by the tax to her citizens engaged in the industry in Bolivian territory, but Bolivia continued the tax and war ensued in 1879. Peru was in alliance with Bolivia at that time and hence became involved in the fight with Chile. The war lasted until 1883 when peace was declared. Chile had been victorious on all sides, and after the war she annexed the two southern provinces of Peru, known as Tacna and Tarapacá, and the Bolivian province of Antofagasta, thus adding not only several hundred miles to the northern extension of her possessions, but also gaining control of all the known nitrate districts of the west coast of South America.

After the close of the war, the nitrate industry became much more active than formerly. New capital poured into the country and the deposits were rapidly developed. Mr. G. B. Chase, of the United States, and Colonel J. T. North, of England, were among the most active foreign operators, while the Chileans themselves were very energetic in developing the region. The Germans also have acquired large interests in the nitrate fields and are active operators, but the English companies are by far the most numerous of all. Though Americans were among the pioneers in the industry, their operations at present are small compared with those of the English, Germans, and Chileans.

NATURAL FEATURES OF THE NITRATE REGIONS

Chile extends along the west coast of South America in a long narrow belt from Peru southward to Cape Horn, a distance of almost 3,000 miles. In width it varies from less than 100 miles to rarely over 200 miles. It is essentially a mountainous region, being occupied on the east by the main range of the Andes, and on the west by the Coast Range. The Andes rise in rugged peaks to altitudes of from

10,000 to over 20,000 feet, while the Coast Range is lower, from 3,000 to 7,000 feet, though sometimes more. The Coast Range is often characterized by rounded summits and smooth slopes, in marked contrast with the bold angular contour of the Andes. In some places the Coast Range is prominently marked, while in others it is little more than the escarpment of an interior plateau as it breaks off to the sea.

Both the Andes and Coast Range follow a general north-and-south course, and between them is an intervening belt of lower country known as the central or longitudinal valley. This so-called valley, however, is not a single continuous drainage area bordered by two mountain ranges as might be supposed, but is a series of elevated basins, forming rolling plains or plateaus, more or less separated by transverse ranges, and draining independently of each other into the Pacific Ocean. In some places the mountains on the east and west approach so closely to each other that their foothills blend together, almost obliterating the intervening basin region; in other places they separate, and the basin region broadens out to many miles in width (see map, Fig. 1).

In northern Chile this basin region is especially well marked in the provinces of Tarapacá, Antofagasta, and northern Atacama. It is here an elevated arid country and includes the Tamarugal Desert on the north and the Desert of Atacama on the south.[1] It is of a generally flat or undulating character, from less than 2,500 feet to over twice that height above the sea, and studded with small, rounded hills, some of which rise considerably higher than the surrounding plateau (see Fig. 2). Its surface is dry and sandy, very few streams intersect its parched expanse, and vegetation is almost totally absent.[2] This region is known as the *pampa,* a term applied somewhat indiscriminately not only to the whole arid region, but

[1] The Tamarugal Desert includes most of the interior basin region of the province of Tarapacá and the northern part of the province of Antofagasta. The Desert of Atacama includes the southern part of Antofagasta and the northern part of the province of Atacama.

[2] Farther south, in central Chile, the basin or valley region becomes a rich fertile country under the influence of the plentiful rainfall there; and still farther south, in southern Chile, where the basin region is more or less submerged in the ocean, the rainfall increases so much as to make one of the wettest parts of the world; but in this northern section the dry desert character of the country is its distinguishing feature.

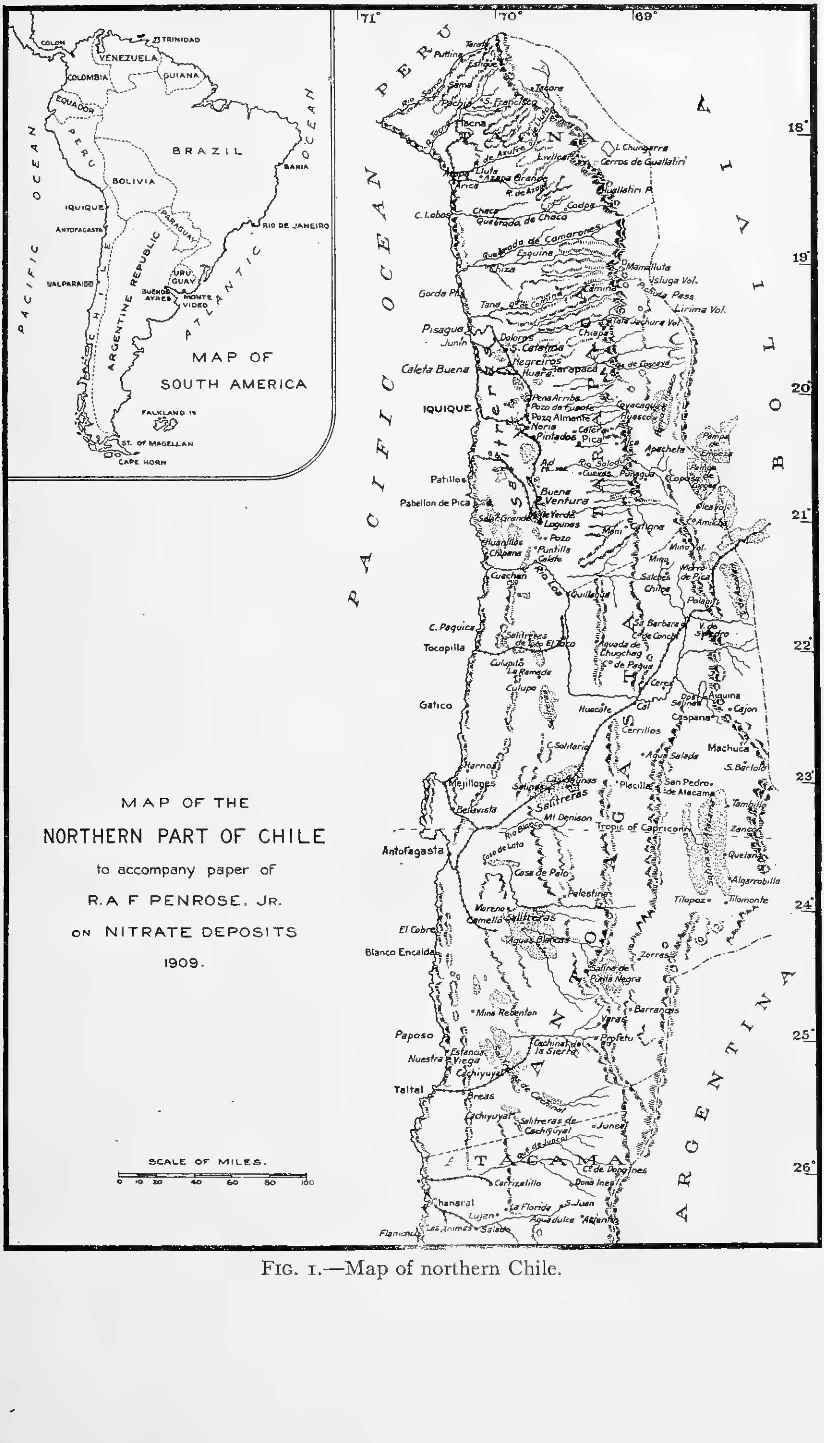

FIG. 1.—Map of northern Chile.

also to special parts of it, either large or small. Thus the term Tamarugal Pampa applies to a large part of the basin of Tarapacá and northern Antofagasta, while the term Tarapacá Pampa applies only to the part of the basin region in the province of that name; and the terms Huara Pampa, El Toco Pampa, Taltal Pampa, and many others apply to purely local districts.

Rain is very rare in the pampa, frequently three or four years, and sometimes eight or ten years of unbroken drought occurring. The Coast Range in this part of Chile is almost as dry as the pampa, though fogs from the ocean are common, and their moistening influence encourages the growth of a little grass and a few cacti on the tops of the hills. Even the fogs, however, rarely reach the pampa. Many streams flow westward from the Andes, but most of them rapidly evaporate or sink below the surface when they come to the pampa, and hence a map of the region shows them suddenly terminating at the foot of the mountains (see map, Fig. 1). The waters that sink continue westward underground, occasionally rising near enough to the surface to form oases in the desert, and then disappearing again. In times of high water, some streams reach the sea on the surface, but only very few do so perennially. Sometimes during seasons of great rises in the rivers of the Andes, the pampa is flooded over large areas. Such occurrences are rare, though some have been recorded, and evidence of them is seen in the dry gullies running across the pampa and in the local accumulations of drift wood from the Andes. In past ages these floods were probably more frequent than now, but the normal condition of the pampa today is one of great aridity. The very presence of nitrate deposits is evidence of the extreme dryness of the region, for nitrate is easily soluble, and water would soon dissolve it and carry it away. The only vegetation is in a few isolated spots where underground streams rise near enough to the surface to support the growth of a little grass or a few stunted trees. Elsewhere the pampa is a sandy desert, from which an impalpable dust rises in blinding clouds with the slightest wind and where the drifting sands form immense dunes similar to those seen on the coast.

The surface of the pampa is composed mostly of sand, clay, and gravel, with masses of more or less rounded rock fragments scattered

FIG. 2.—Typical view in the pampa of the province of Tarapacá, Chile, showing the nitrate deposits near the base of the low hills, and the Coast Range in the far distance.

over it, and frequent deposits of saline materials. Through these loose materials frequently protrude isolated hills and knolls of stratified and igneous rocks similar in nature to many of the rocks found in the adjoining mountain ranges; and doubtless rocks of like character underlie the loose sediments of the pampa. The surface materials of the pampa are probably of post-Tertiary age and represent an old sea bottom formed by the deposition of sediments in a now extinct inland sea, or a series of lakes, which once extended from the Andes to the Coast Range, over the whole extent of what is now the pampa.

The Coast Range bordering the pampa on the west is composed of a variety of rocks varying greatly in different places from Tarapacá southward through Antofagasta and Atacama. Old crystalline rocks, including gneisses, granites, etc., frequently occur. Stratified rocks of probably both Paleozoic and Mesozoic ages, including sandstones, limestones, and shales, are abundant in many places, and are much folded, contorted, and broken. They are intersected in many places by igneous intrusions. As we cross the pampa and approach the Andes, both stratified and igneous rocks again appear through the loose sediments; and in the high Andes immense areas of late volcanic flows are found.

MODE OF OCCURRENCE OF THE NITRATE DEPOSITS IN THE TARAPACÁ REGION

The pampa region has a general slope from east to west, that is, from the foot of the Andes to the foot of the Coast Range, though it is so gradual as to be often unnoticeable to the eye. As a result of this slope the lowest part of the pampa is along its western border, where it abuts against the Coast Range foothills. It is along this zone that the nitrate deposits occur, and in the province of Tarapacá they occupy a narrow north-and-south belt following this position for over one hundred miles. The surface of the pampa is here almost always impregnated with more or less saline matter, which sometimes becomes so abundant as to form beds several or many feet in thickness. These are practically superficial deposits, though they are sometimes capped by earthy materials for some feet in depth. Their surface, when exposed, often presents a rough and more or less

leached appearance, due to the action of the rains and floods which at rare periods visit the pampa (see Fig. 3). Sink holes, due to the same cause, are not infrequent. Most of the deposits consist of common salt (sodium chloride) or of nitrate (sodium nitrate), or of both mixed together; while other saline materials occur more sparingly. The salt beds are called by the Chilean *salares* and the nitrate beds, *salitreras*. The material composing the nitrate beds is known as *caliche*.

Though both common salt and nitrate occur in very large quantities, the former is by far the more abundant, and covers immense flats for many square miles in area along the western edge of the pampa. Sometimes it is in comparatively pure beds, sometimes it is mixed with clay, sand, and gravel, and sometimes it only impregnates the surface of the pampa. These salt beds have not yet been extensively explored, but they probably vary from a mere crust to several or even many feet in thickness. The salt is not much used, though a little is obtained for local consumption and is refined by dissolving and evaporating the solution.

The nitrate deposits, though less extensive than the common salt deposits, are far more important commercially. Like them, they occur in the low zone along the western edge of the pampa, but while the salt flats are usually in the very bottoms of the basins, the nitrate deposits are usually on a little higher ground. Sometimes the nitrate deposits also occupy the bottoms of the basins, but their typical position is on the lower slopes of the hills and ridges, forming terraces or benches around the salt flats, and from a few feet to perhaps one hundred feet or more above them. Sometimes there may be nitrate upon the slopes and no salt in the flats, and sometimes there may be salt in the flats and no nitrate on the slopes, while sometimes the deposits of the two materials are more or less indiscriminately mixed or may underlie or overlie each other; but in many cases we find them both occupying the respective typical positions just mentioned. The slopes on which the nitrate often occurs rise at low angles and are sometimes scarcely distinguishable from the surrounding flat country.

The nitrate deposits are of very variable thickness even over small areas, and in one spot there may be several feet of the material, while within a few yards there may be only a few inches, or none at all.

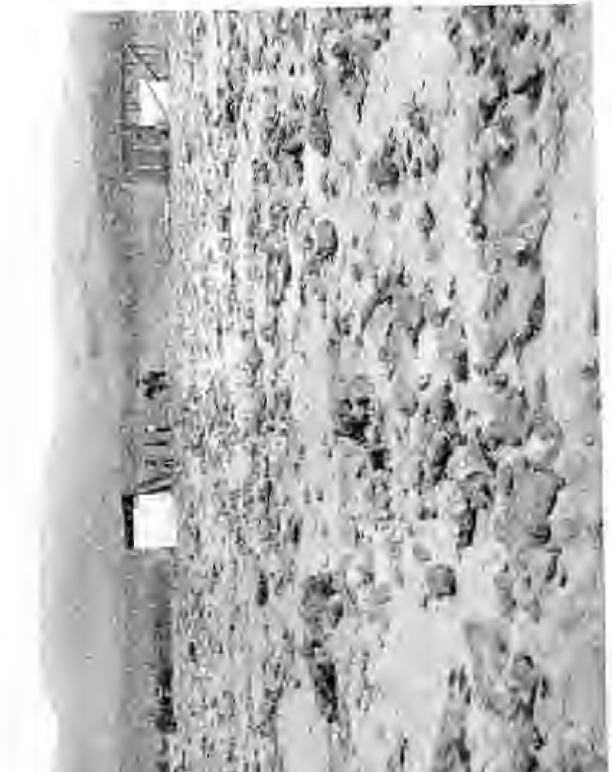

Fig. 3.—View in the pampa of the province of Tarapacá, Chile, showing characteristic surface features of the salt and nitrate deposits.

A thickness of from 1 to 1½ feet is common, of 2 to 3 feet is less so, but not unusual, and of 4 to 6 feet is very unusual. Where the surface of a deposit is not too heavily covered with earthy materials, it often has a moist appearance due to the deliquescent character of the nitrate or perhaps to the presence of calcium chloride.

The nitrate deposits are usually covered by a capping composed of sand, clay, gravel, and rock fragments, from a few inches to many feet in thickness. In a few places this capping is absent and the nitrate is covered only by a thin coating of desert dust, but usually the overlying material is from 2 to 20 feet in thickness and sometimes, though rarely, 30 to 40 feet. This capping is called *costra* and is generally more or less indurated; the usual condition being alternating layers or patches of harder and softer material, and an extreme condition being that of a hard mass like a breccia or conglomerate, in which the cementing material is nitrate and other saline and earthy substances. The rock fragments are angular or partly rounded and vary from the size of grains of wheat to masses of a foot or more in diameter, pieces from a half-inch to 3 inches in diameter being the most common. The fragments consist of limestone, shale, sandstone, igneous rocks, etc., the preponderance of one or the other varying in different places. They seem to some extent to vary in character according to the nature of the rocks *in situ* in the neighborhood, and seem to have been derived largely from the slopes of the Coast Range hills and from the small knobs protruding up through the pampa. The costra is often overlaid by from a few inches to a few feet of loose, wind-drifted material called *chuca*.

In some places there is a sharp line of demarkation between the costra and the nitrate; in others they seem to blend into each other. In fact, they often seem to represent one and the same deposit, rich in nitrate at the base and poor in nitrate above. The smaller quantity of nitrate in the costra than below may possibly be due to impoverishment by leaching during the rare periods of rainfall or flood. In a few of the mines where the rich part has been exhausted, the costra has been worked as a source of nitrate. Underlying the nitrate is an earthy material of a brown or buff color, generally soft and powdery though sometimes sandy, gravelly, or indurated, called *coba*. Below

the coba is the great series of interbedded sands, clays, and gravels which underlie the broad expanse of the pampa.

A general section of the nitrate deposits in Tarapacá, therefore, would show the following succession of formations:

"Chuca" (loose, wind-blown material, dust, sand, gravel, etc.)	0–several feet
"Costra" (capping of the nitrate beds)	0–20 or even 30 or 40 feet
"Caliche" (crude nitrate)	0–6 feet
"Coba" (earthy floor of nitrate beds)	Indefinite (perhaps a few feet)
Stratified sands, clays, and gravels	To great depths

In a few places the nitrate occurs as a fringe around the edges of the isolated knobs of rock that rise up through the pampa, and rests either on the solid rock or on the detritus of the hillside, but its usual occurrence is overlying the earthy materials described above.

MATERIALS COMPOSING THE NITRATE DEPOSITS IN THE TARAPACÁ REGION

The nitrate occurs in the form of sodium nitrate with the formula $NaNO_3$, though very small quantities of other nitrates are sometimes found with it. It generally occurs as a translucent mass, sometimes in a coarsely or minutely crystalline aggregate of rhombohedra; sometimes in a stalactitic or mammillary form, or as an efflorescence or incrustation. When pure, it is of a white color, but is often yellow, red, brown, or purple from impurities. Frequently it is much streaked or spotted a dirty brown color due to sand or clay, and sometimes it is so mixed with earthy matter as to have a chocolate-brown appearance throughout. The crude material, as already stated, is known by the Chileans as caliche. Its mineralogical name is soda niter or nitratine. Sometimes it is called cubic niter or cubic saltpeter, because on casual inspection its rhombohedral crystals seem closely to approach the form of cubes. Commercially it is often known as Chile saltpeter, as distinguished from plain saltpeter, or niter, which is potassium nitrate.

The nitrate deposits are never composed of perfectly pure sodium nitrate, that material forming usually only from a small percentage up to rarely as much as 70 per cent. of the whole mass. Crude nitrate containing 25 per cent. of sodium nitrate is considered a fair grade of raw material, one containing 50 per cent. is considered high,

and one containing 60 or 70 per cent. is very rare, though of course in selected specimens even 90 per cent. or more of sodium nitrate may be found. The impurities are sand, clay, gravel, and rock fragments, with a very variable admixture of saline materials. The rock fragments are similar to those already described in the costra, overlying the nitrate. In some places they are scattered only sparingly through the deposits; in others they are so numerous as to form a breccia or conglomerate with the nitrate as a matrix.

The saline impurities in the nitrate are mostly common salt (sodium chloride), with variable amounts of sodium sulphate (Glauber salts) and calcium sulphate, the latter often occurring as crystalline gypsum and perhaps also as anhydrite. In addition, there occur sodium and calcium borates, as well as carbonate, chloride, and other salts of calcium, and various salts of aluminum, magnesium, potassium, ammonium, and a small but very constant quantity of sodium iodate. Bromine compounds, together with other materials in small quantities, are sometimes, though more rarely, present. The common salt (sodium chloride) occurs in varying amounts in all the nitrate deposits, sometimes in very large quantities, and we find all gradations in admixture from deposits composed mostly of nitrate to deposits composed mostly of salt. The other saline materials are in comparatively small amounts, though in special cases some of them may be more abundant than the common salt.

The following analyses represent the composition of samples of crude nitrate (caliche) from different localities. The analyses were made in Chile by Mr. D. G. Buchanan, chemist of the Alianza Company, and were kindly sent to the writer by Mr. J. F. Comber, manager of the North Lagunas Company.

The saline impurities in the crude nitrate are generally purely mechanical admixtures, like the salt, but sometimes they are associated with the nitrate in certain proportional relations, forming distinct minerals. Thus we have darapskite and nitroglauberite, both minerals consisting of hydrous nitrates and sulphates of sodium. Moreover, both the nitrogen and the iodine occur in small quantities in other combinations than with sodium. Small amounts of potassium nitrate are often found, while calcium nitrate (nitrocalcite) and barium nitrate (nitrobarite) as well as calcium iodate (lautarite) and

a calcium iodo-chromate (dietzeite) also occur. These and other rare combinations that are found in the region are, however, in small quantities and are only mineralogical curiosities.

The iodine in the crude nitrate is an important material on account of its commercial value. It is a very constant ingredient in the deposits, though in minute quantities, generally only a fraction of 1 per cent., and occurs usually in the form of sodium iodate, though a little sodium iodide has also been found. Sometimes the iodine is

ANALYSES OF CRUDE NITRATE (CALICHE) FROM CHILE

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sodium nitrate..........	28.54	53.50	41.12	61.97	22.73	24.90	27.08
Potassium nitrate........	trace	17.25	3.43	5.15	1.65	2.50	1.34
Sodium chloride.........	17.20	21.28	3.58	27.55	41.90	24.50	8.95
Calcium chloride........	.....	.....	.....	.....	.....	.....	5.25
Magnesium chloride.....	.....	.....	.....	.....	.....	.....	0.18
Potassium perchlorate ..	trace	0.78	0.75	0.21	trace	trace	trace
Sodium sulphate........	5.40	1.93	trace	2.13	0.94	6.50	none
Magnesium sulphate.....	3.43	1.35	10.05	0.15	3.13	6.50	none
Calcium sulphate........	2.67	0.48	3.86	0.41	4.80	4.50	2.89
Sodium bi-borate........	0.49	0.56	0.20	0.43	0.53	0.15	0.52
Sodium iodide..........	0.047	.....	.....	.....	.....	.....	.....
Sodium iodate..........	0.043	0.01	0.05	0.94	0.07	0.054	0.08
Ammonium salts........	trace	trace	trace	trace	trace	trace	trace
Sodium chromate........	.....	trace	.....	distinct traces	trace	.....	.....
Insoluble matter.........	40.30	2.07	31.86	0.39	22.50	28.40	47.34
Combined water, etc.....	1.88	0.79	5.00	0.67	1.75	2.00	6.37
	100.00	100.00	100.00	100.00	100.00	100.004	100.00
Total nitrates calculated as sodium nitrate......	28.54	68.00	44.02	66.29	24.11	27.00	28.20
Total chlorides calculated as sodium chloride	17.20	21.28	3.58	27.55	41.90	24.50	14.70
Total iodine............	0.067	0.0064	0.036	0.604	0.045	0.035	0.051

more abundant in the salt deposits than in the nitrate deposits, but the market demand is supplied by what is obtained as a by-product in refining the nitrate, and hence the salt is not worked for iodine. Borates occur in many places throughout the arid region of the pampa, mostly in the form of the hydrous borate of sodium and calcium known as ulexite or boronatrocalcite, or in the form of the hydrous calcium borate known as colemanite. In places these materials have been worked to a very considerable extent. Some sodium bi-borate is also found. Sodium sulphate occurs in large deposits

in parts of the pampa, especially in Antofagasta, but is not worked on account of the limited demand for it. There are many materials in the pampa, such as potassium salts, etc., which would be of great value if found in quantities, but, so far as yet known, they occur too sparingly to be of any considerable commercial importance.

To summarize, it may be said that the commercial products of the pampa are mostly sodium nitrate, with comparatively small, but commercially very important, quantities of iodine; while common salt is obtained on a small scale for local use, and borates have been produced in varying quantities at different times, often in very important amounts. The production, however, of all the other saline materials in the pampa is insignificant in importance compared with that of sodium nitrate.

OTHER NITRATE REGIONS IN CHILE

As already stated, almost all the nitrate of Chile is in the great arid basin lying between the Andes and the Coast Ranges, in the provinces of Tarapacá and Antofagasta. South of the nitrate fields of Tarapacá, already described, the main pampa region extends through the province of Antofagasta and here several large nitrate fields occur. A number of transverse ridges, or ranges of hills, intersect this region, forming more or less separated basins, and it is in these that the nitrate occurs. The different basins are designated as different pampas, but all of them are simply parts of the general pampa region.

The El Toco Pampa is in the northern part of the province of Antofagasta, and here large deposits of nitrate are actively worked. The refined product is shipped from Tocopilla, a seaport about 120 odd miles south of Iquique, and connected with the nitrate district by a railway. Farther south in the same province are the Antofagasta Pampa and the Aguas Blancas Pampa. Both are large producers of nitrate, and are connected by railway with the port of Antofagasta, which is the shipping-point for the nitrate from these districts and is an important city of about 20,000 people. Recently also a new port called Mejillones, a few miles north of the port of Antofagasta, has been improved and connected with the railway running into the nitrate fields, in order to facilitate shipments. Still farther south,

in the extreme southern part of the province of Antofagasta, is the Taltal or Cachinal Pampa, where large quantities of nitrate are also produced. A railway connects this district with the coast at Taltal, which is a prosperous seaport in the southern part of the province of Antofagasta and the shipping-point for the Taltal district.

Though most of the nitrate deposits of Chile are in the provinces of Tarapacá and Antofagasta, yet some have been found to the north and south of these limits. As yet, however, they have not become of great importance. In the province of Tacna, to the north of the province of Tarapacá, several small pampas represent a northerly continuation of the general pampa region, and a few small nitrate deposits have been found there. South of the province of Antofagasta, isolated nitrate deposits have been reported in places in the northern part of the province of Atacama, but the extent of the deposits is not yet well defined.

ORIGIN OF THE NITRATE DEPOSITS OF CHILE

The discussion of the origin of the nitrates of Chile involves chiefly the source of the nitrogen, and many suggestions have been advanced to explain its presence, but its derivation from organic matter, and especially from guano, seems the most probable hypothesis. Among some of the other hypotheses that have been suggested may be mentioned the following:

It is a well-known fact that electric storms have the power of causing the oxidation of the nitrogen of the air with the formation of nitric acid. It has been suggested by some that such storms in the Andes have generated nitric acid, which, coming in contact with the limestone found in places in the mountains, has formed calcium nitrate; and that this has in turn been converted to sodium nitrate by contact with sodium salts found in the pampa region.

It has also been suggested that the nitrogen of the nitrates was derived from nitrogenous fumes from volcanoes in the Andes.

A. Pissis[1] quotes authority to show that alkaline carbonates have the power "of transforming atmospheric nitrogen into nitric acid in the presence of other oxidizable matters." He points out that the decay of feldspar in the rocks of the region has supplied a source

[1] *Nitrate and Guano Deposits in the Desert of Atacama*, London, 1878, p. 16.

of alkaline carbonates, that the protoxide compounds of iron, which are common in the rocks of the pampa, are easily oxidized under ordinary conditions forming peroxide compounds of iron, and he thinks that the alkaline carbonates, under such environment, have caused the oxidation of the nitrogen of the air with the ultimate formation of nitrates.

David Forbes[1] thinks that the nitrates were derived from the decay of vegetation around and in salt water swamps and lagoons, which he believes once occupied the site of the present pampa. A certain amount of nitrogenous matter might be derived in such a manner, and this subject will be discussed again later on.

It seems, however, as if a source of nitrogen more abundant and ready than any of those mentioned might have existed in the immense accumulations of guano which for ages have been characteristic of this coast, and this suggestion has been offered by a number of other writers. Incidentally it may be stated that in many parts of the world, especially in warm regions, nitrates are found in small deposits in caves, in association with bat guano, and that the source of the nitrogen from this guano is very generally recognized.[2]

It is well known that the part of the coast of Chile where the nitrates occur has been gradually rising in recent geologic times, and that the pampa region already described was once a part of the ocean bottom. During this elevation, as the region gradually rose up to, and then above, the ocean level, it probably passed first through the condition of an open bay or gulf, then became more and more separated from the ocean, and finally, when raised completely above it, became a more or less inclosed interior basin occupied by an inland sea, or a series of basins occupied by salt lakes, lying between the Andes and the Coast Range. Guano beds were doubtless deposited along the borders of these waters, just as they are now deposited on the neighboring shores of the Pacific.

Guano consists largely of nitrogenous materials, phosphates, and water, with other substances in smaller quantities. The nitroge-

[1] "On the Geology of Bolivia and Peru," *Quarterly Journal of the Geological Society of London*, Vol. XVII (1860–61), pp. 13–16.

[2] A. Muntz et V. Marcano, *Académie des Sciences, Comptes Rendus*, Vol. CI (1885), pp. 65–68. See also A. Muntz, *ibid.*, pp. 1265–67.

nous materials consist mostly of ammonium salts, especially of urate of ammonium, and other urates, together with guanine[1] and variable quantities of nitrates and nitrites, as well as with various other organic products resulting from decayed animal matter. It is a well-known fact that, under suitable conditions, the nitrogen of all these materials that are not already in the form of nitrates, passes eventually into that form through the agency of certain microscopic organisms (bacteria). These bacteria are of many different kinds, and different ones act at different stages in the transition. The action, when other conditions are favorable, goes on most efficiently in the presence of alkalies, or of alkaline earths like calcium carbonate, etc., which are abundant in the pampa region.

It seems probable that the nitrates of Chile were mostly produced in this way from nitrogenous animal matter of old guano beds which once lined the waters of the interior basin, and which have long since disappeared under the influence of erosion. The nitrates were probably carried down into the waters of the basin and became mixed with the other saline materials already there. The waters probably began to diminish in volume shortly after their separation from the sea, for though they received the drainage of the surrounding land, this was not enough to compensate for the loss by evaporation. The evidence tends to show that the rainfall in those early days was more abundant in this region than at present, but it gradually grew less and its constant diminution doubtless hastened the process of desiccation.

Thus the waters gradually sank until they fell below the level of any outlet they may have had to the ocean, and then, the drainage being cut off, the materials in solution became more and more concentrated as desiccation progressed. These materials consisted of the original salts of the sea water, the nitrates and other salts from the guano beds, and other materials constantly carried down from the surrounding land. The concentration continued until the waters became saturated with saline materials, and then deposition began along the edges and on the bottom. Eventually the whole body of water disappeared and the dry desert pampa with its deposits of nitrates, common salt (sodium chloride), and other materials alone

[1] Guanine is an organic base containing nitrogen and having the formula $C_5H_5N_5O$.

remained. The occurrence of the nitrate in the form of sodium nitrate is probably due to the abundance of sodium salts in the region.

The occurrence of the nitrate and other saline deposits along the western edge of the pampa, where the latter is lowest in altitude, may be due to one or both of two causes:

1. The pampa, sloping as it does from east to west, gradually caused the last of the waters of the inland basin, as they evaporated, to collect along its western edge. If the nitrate in solution had not become sufficiently concentrated to cause deposition before that time, the deposits of course would be formed only on the west side.

2. If, however, deposition had begun while the waters still washed the slopes of the Andes, the greater rainfall there than on the west side of the pampa may have dissolved the nitrate from the east side and allowed it to be carried down into the loose soil of the pampa, or else over to the west side, where it was again deposited as the waters evaporated.

As against the hypothesis of the derivation of the nitrates of Chile from guano, the objection has been made that guano beds, and the remains of dead birds such as generally occur in them, are often notably absent in some of the nitrate districts. Very little guano is found with the Tarapacá nitrates, but in Antofagasta it does occur in the same region as some of the nitrate deposits. The scarcity of guano at present in some of the regions is easily explained, for the birds which formed it were essentially sea birds, dependent upon fish for food. As the waters of the inclosed basin gradually evaporated they became too saturated with saline matter for fish to live in them, so that the birds had to abandon their old haunts in the basin and seek other regions for their sustenance. Hence, though immense accumulations of guano had probably been formed, no new supply was maintained, and ample time has elapsed for the old guano to have been carried away, as already described, and for the bones, etc., to have disintegrated. The fact that guano is still abundant in parts of the nitrate regions of Antofagasta and not so in Tarapacá probably indicates that the birds left the latter region at an earlier date than the former, or that the conditions for its preservation were better in Antofagasta than Tarapacá.

The notable absence of seashells and remains of other marine

life in the nitrates of Tarapacá, may be explained in a manner similar to that suggested for the absence of guano, that is, the water became too heavily charged with saline matter for such life to exist, and the remnants of what had previously existed were gradually destroyed or were covered up by later pampa deposits.

If the nitrate was derived, as already described, from old guano beds long since disintegrated and eroded, then we might expect to find phosphates from the same source concentrated somewhere on the pampa; but such, so far as known, is not the case, though of course phosphates are found in the still existing later guano. Perhaps, however, phosphates from the old eroded guano may exist, and may not yet have been discovered, as the pampa has been but little studied outside its nitrate deposits. As the phosphates in guano are both soluble and insoluble, some of the former derived from the old guano may possibly have percolated into the limestone existing in parts of the region, forming insoluble calcium phosphate, such as occurs in coral formations in the West Indies and the South Sea Islands; while perhaps some of the insoluble phosphates resulting from the old guano may yet be found among the sediments of the sea bottom which now forms the pampa.

It is possible that in addition to the nitrate derived from guano, a small amount of it may have been derived from the decay of the marine and land vegetation of the interior basin. This decay would set free nitrogenous vegetable materials from which nitrates might have been formed, just as from guano. Nitrogen, however, is much more abundant in guano than in vegetable matter, and, therefore, the probability seems to be that guano was by far the more important source of the nitrates. Marine vegetation, however, probably played a most important part in supplying the iodine found in the region.

The source of the iodine in the nitrate and salt deposits of the pampa has been a much-discussed subject. Iodine is a constituent of many minerals and is found in many mineral springs, as well as in minute quantities in sea water. It also enters in small but appreciable quantities into the composition of certain marine plants and some sea animals. In fact before the iodine of Chile came into use, most of the iodine of commerce was extracted from

certain forms of seaweed or kelp. Iodine is taken up by such plants from the sea water and fixed in their tissues.

The iodine may, therefore, have come either from sources on the land or in the water or both. As yet no strong evidence has been produced to show that it came from the land. On the other hand, we have no definite evidence that it came from marine sources, but at the same time we know that the pampa was formerly probably covered by a body of sea water, at first connected with the open ocean and later cut off from it. During the time that it was more or less directly connected with the ocean an immense accumulation of iodine-bearing marine plants may have grown there, gradually collecting the iodine not only from the limited quantity of water represented by the arm of the sea in which the plants grew, but also from a constant fresh supply of sea water circulating in and out from the ocean, or dashed over a possible dividing barrier during storms and high tides. Possibly also similar marine plants from the open ocean may have come in with this sea water and accumulated, in a manner similar to that seen in many parts of the world today, thus augmenting the marine plants already growing there. After the region had been completely cut off from the ocean and desiccation had progressed sufficiently, this marine flora would decay and thus afford a great quantity of iodine. The simple evaporation of the water of the inclosed basin would of course account for some of the iodine, as this material is universally present in sea water, but in quantities so extremely minute that it seems necessary to suppose that the iodine of the pampa has been segregated from far larger quantities of water than those of the basin alone.

Hence, though the possibility of the source of the iodine from the decay of iodine-bearing minerals or springs on the land cannot be denied, yet the facts at hand suggest more strongly a source from marine plants.

As regards the borates found in the pampa, it may be said that, like the borates found under similar conditions in many other arid regions, they were probably derived mostly from the decay of boron-bearing minerals and from springs carrying boron compounds, such as are common in many mountainous regions, and especially those of igneous origin. Boron compounds occur also in sea water and

in some plants, but in quantities so extremely minute as to make such sources answerable for only a very small amount of the borates of the pampa. On the other hand, when we consider the vast areas of igneous rocks in the Andes and even in the Coast Range, the source mostly from boron-bearing minerals and springs seems very plausible. The boron materials from such sources were probably carried down into the waters of the inland basin, where they were concentrated and deposited in the same manner as the other saline materials.

In concluding the subject of the origin of the nitrates and other saline deposits of the pampa, it must be said that the present discussion is intended only as a most brief and general one. A vast amount of geological and chemical details must be worked out both in the field and the laboratory before the subject can be fully understood. The determination of the exact conditions of deposition and the various chemical transitions through which the saline materials have gone, require far more data than are at present available.

INDUSTRIAL FEATURES IN THE TARAPACÁ REGION

Mining and refining of nitrate.—Mining in the nitrate regions is done in surface openings. The capping of costra is thrown aside and the nitrate below mined and raised to the surface (see Figs. 4 and 5). The quantity of nitrate often varies greatly in different parts of a deposit and the change from rich spots to lean spots is often very abrupt, so that nitrate is usually worked in isolated pits or short trenches on the spots where it is richest, and not in long trenches running systematically through the deposit, as would be the most economical way if the deposits were uniform. Hence, most properties that have been extensively worked present the appearance of an upturned tract studded with numerous pits, some close together and some more or less separated. In some cases, where the capping of costra is hard and compact, or very thick, the miner finds it easier to go under it in search for nitrate than to remove it, and thus small underground workings in the form of caves have sometimes been formed, but these are the exception, and the usual mining is in open pits.

When the richest parts of a deposit have been exhausted, the miner

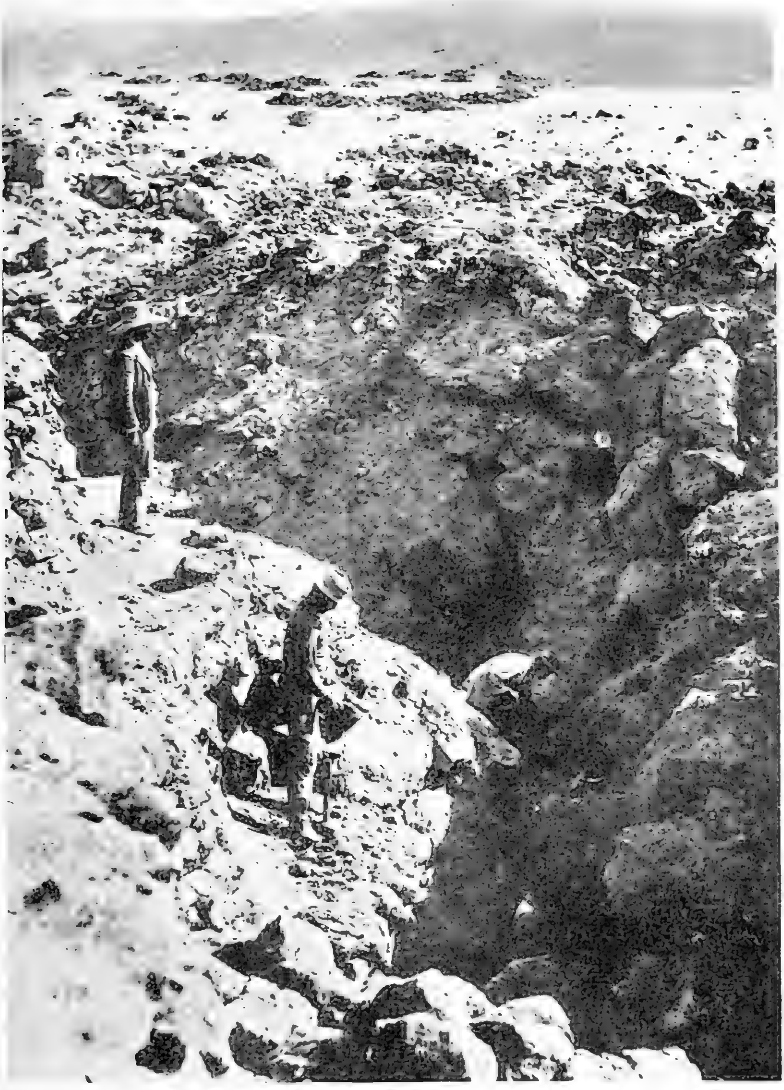

FIG. 4.—Nitrate mining in the province of Tarapacá, Chile.

often goes over the property again more carefully in search of what is left. In this way many properties have been worked over several times, and lower-grade material has been taken each time. In a few cases, even the costra, when it contains an unusual amount of nitrate, has been used after the purer parts of the deposits have been exhausted.

In the early days, only the richest of the deposits were worked, and only crude nitrate running as high as 40 or 50 per cent. in sodium nitrate was mined, but now much lower grades are worked, and the average of the crude material used in the Tarapacá region today would run, perhaps, below 25 per cent. in nitrate. Of course both richer and poorer material is also worked, and in certain places crude nitrate running even as low as 10 per cent. is utilized in admixture with higher-grade material.

The crude nitrate is hauled in carts or on tramways from the mines to the refineries, where it is coarsely crushed and the nitrate separated from the impurities by a process of leaching with hot water. The refined product usually contains about 95 per cent. of sodium nitrate, which is the standard of purity for the nitrate shipped from the district. Sometimes a still higher-grade product is made for special purposes. The nitrate is put in large sacks, and sent to the coast for shipment to various parts of the world. Sodium nitrate is deliquescent, so that when exposed to the moist air on board ships it cakes and the sacks stick together, often forming a solid mass which has to be taken out of the ships with picks.

The method used in extracting the nitrate is very crude, only from 60 to 70 per cent. of it being saved, and the average loss of nitrate in the Tarapacá region in refining is said to be about 35 per cent. Those in authority claim that under present conditions, the nitrate that is lost could not profitably be saved, but the time may come when the crude nitrate will show signs of exhaustion, and then probably less wasteful methods will be devised, and the loss will be cut down. At present, the supply of crude material is so vast that such economy has not been forced on the producers.

The iodine is obtained from the solution (mother liquor), after the nitrate has been taken out, by concentrating it and treating it with sodium sulphites, which precipitate a black powder consisting

mostly of iodine. This is then sublimed and condensed, when it is deposited in black scaly flakes of crystalline iodine.

FIG. 5.—Nitrate mining in the province of Tarapacá, Chile.

The water for the nitrate works is obtained mostly from wells in the pampa, and is often gotten in considerable quantities at depths

of from 50 to 100 feet. Some water is also obtained by piping from the foot of the Andes.

Companies, towns, cities, and railways.—The nitrate industry is carried on largely by companies, and the establishments at which their operations are conducted are known as *oficinas*. Among some of the best-known oficinas in Tarapacá are the Alianza, Agua Santa, Camiña, Josefina, La Granja, Central Lagunas, North Lagunas, South Lagunas, Puntunchara, Puntilla de Huara, Rosario de Huára, Ramírez, Santa Lucía, Santiago, Unión, and many others. In 1907 there were almost one hundred oficinas in the Tarapacá region and about one hundred and fifty in all Chile (see Fig. 6).

Many small towns have grown up on the Tarapacá Pampa as a result of the nitrate industry, among them being Dolores, Santa Catalina, Negreiros, Huara, Pozo Almonte, La Noria, Lagunas, Tapiga, San Antonio, etc. The oficinas that are not at any of the towns have become small communities in themselves, with large capacious buildings for the administration of the works, houses for the employees, stores, schools, etc.

The chief ports for the shipment of the nitrate of the province of Tarapacá are Iquique on the south and Pisaqua on the north, the former being by far the more important and the real headquarters of the nitrate trade of this province. They are both connected with the nitrate fields by railway. Iquique is a flourishing city of about 50,000 inhabitants (see Fig. 7), and Pisaqua has about 5,000. Smaller ports from which Tarapacá nitrate is shipped are Junín and Caleta Buena, both lying between Iquique and Pisaqua. Farther south, the seaports of Tocopilla, Antofagasta, Taltal, etc., are important shipping-points for the nitrates of the province of Antofagasta.

The Nitrate Railways Company (an English corporation) owns a line running inland from Iquique to the Tarapacá Pampa and then branching out through the nitrate fields. It intersects the pampa from Pisaqua on the north to Lagunas on the south, a distance in a straight line of over one hundred miles and much farther as the railroad goes, besides having many lateral branches, its aggregate length being about three hundred miles. Many of the nitrate works located to one side or the other of the railroad are connected with it by branch

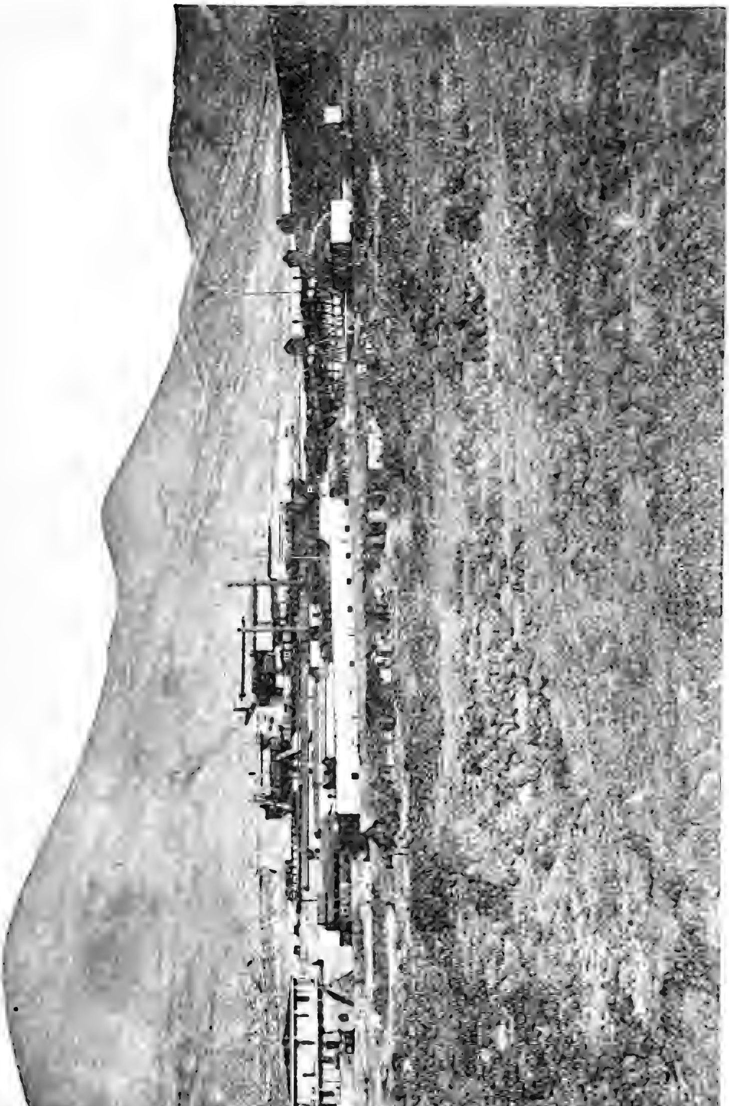

Fig. 6.—Nitrate works in the province of Tarapacá, Chile.

lines or by tramways worked by mules, and some of the nitrate companies have their own railways to the coast.

Nitrate production.—For a large part of the time in recent years, most of the large nitrate producers have been in a combination (Combinación Salitrera), which limits the output of refined nitrate and apportions to each company the amount that it may produce annually. This combination has been broken more than once by dissensions among the producers, and as late as March, 1909, after it had been in force for several years, it was again broken. Recent reports, however, are to the effect that strong efforts are being made to renew it. The object of the combination is to keep up the price of nitrate; and the production of iodine is controlled in the same way. The market for iodine is so limited that usually in a few months one company can produce enough to supply its allotment for several years. An organization is maintained to promote the use of nitrate, especially in agriculture, and agents are kept in all the large countries of the world. As a result, the consumption of nitrate is rapidly increasing, and the amount each company is allowed to produce increases correspondingly. The product goes largely to the United States and Europe, with smaller quantities to other countries.

In 1830 the production of nitrate in Chile is said to have been only 8,348 long tons.[1] In 1900 it was 1,473,091 long tons.[2] The combination of nitrate producers now estimates the production from April 1 of one year to March 31 of the following year. The production in this period from 1907 to 1908 was about 1,780,818 long tons, and from 1908 to 1909 it was about 1,808,986 long tons. The value of nitrate varies from year to year, but the price landed in New York or European ports in recent years has ranged between about $40 and $50 per long ton.

Nitrate reserves, taxes, etc.—Numerous estimates have at various times been made to determine the amount of crude nitrate existing in the nitrate regions. These estimates have differed very widely, some showing that the supply would be exhausted at the present rate of consumption in twenty-five or thirty years, others that it would last for three or four hundred years. The cause of this great diver-

[1] *Engineering and Mining Journal*, February 23, 1901, pp. 241, 242.

[2] *The Mineral Industry for 1901*, New York, 1901, p. 588.

Fig. 7.—The city of Iquique, Chile.

gence is due to the premises on which the different estimates have been based. Many of those who predict a short life for the nitrate fields do not allow anything for future new discoveries of nitrates in northern Chile, whereas the probability of this is very great. The Chilean government owns all the nitrate deposits on the public domain and sells them only at auction. This policy has tended somewhat to retard individual effort at exploration, and hence vast regions in the Tamarugal Desert and the Desert of Atacama, which may contain nitrate, have not yet even been explored for it.

The nitrate that is being worked today, moreover, is very wastefully treated, and a large percentage of it is left in the refuse material accumulating around the oficinas; while the costra, or capping of the nitrate deposits proper, which is now only occasionally used as a source of nitrate, as it usually contains too low a percentage to satisfy the present operators, is collecting in vast quantities in the places where it has been mined and piled up to get at the purer material (caliche) below. Thus low-grade nitrate materials are gradually accumulating in immense amounts, and may be used in the future when more economical methods are introduced. These materials, together with the possible new discoveries of nitrate, render the future of the industry in Chile much more hopeful than some of the pessimistic prophets would lead us to believe; and for very many years to come Chile will doubtless be capable of supplying nitrate to the world.

As already stated the Chilean government owns all the nitrate lands on the public domain, and sells them at public auction from time to time, as occasion demands. The government also levies an export tax assessed in Chilean pesos. As the rate of exchange for the peso varies greatly from time to time, the amount of the tax as expressed in American money also varies greatly. A recent statement makes the tax equal to about 56 cents American money per quintel of 101.4126 pounds.[1] The combined revenues from the sales of nitrate lands and from taxes are so great that they pay a large part of the government expenses.

Uses of nitrate.—The nitrate of Chile is used for a number of

[1] These figures were kindly furnished the writer by Mr. Francisco J. Yánes, secretary of the International Bureau of American Republics, Washington, October, 1909.

different purposes, but by far the largest consumption is its use as an agricultural fertilizer, in supplying nitrogen to the soil. One of its earliest uses, and still a source of large consumption, is in the manufacture of niter, or potassium nitrate, for gunpowder. This is done by treating sodium nitrate with a salt of potassium. The nitrate of Chile is also used in the manufacture of nitric acid, and as nitric acid is an important factor in the manufacture of nitro-glycerine, dynamite, and other explosives, the consumption of Chile nitrate for such purposes is large. It is also used for many other chemical purposes on a smaller scale.

The value of sodium nitrate as a source of nitrogen in fertilizers has been known for a long time, but it has been only in comparatively recent years that it has been used on a very large scale. Formerly the nitrogen in fertilizers was supplied mostly from guano, fish scrap, leather scrap, and various other organic materials. The consumption of sodium nitrate in fertilizers now exceeds by many times its use for other purposes, and is rapidly increasing. The exhausted soils of Europe and of some parts of the United States, as well as of other countries, require year by year more fertilizing materials to make up for what is taken away by excessive cultivation, and some available compound containing nitrogen is one of the most important of such materials. Sometimes nitrate is used alone in cases where a nitrogenous compound is all that is needed, but more commonly it is used in admixture with phosphates, potassium salts, and other materials usually needed by depleted soils.

NITRATE DEPOSITS ELSEWHERE THAN CHILE

In parts of the world other than Chile, deposits of nitrates, especially potassium nitrate, and in smaller amounts calcium nitrate, have been found in many places, but nowhere in quantities in any way comparable with the sodium nitrate deposits of Chile, which today supply most of the world's demand. In old times, however, before this source became of commercial importance, potassium nitrate was obtained in considerable quantities in India and other tropical countries, where it occurs, often in association with calcium nitrate, in the soil and the grounds surrounding dwellings. Nitrate was also obtained in many parts of the world in caves, where it is found in

association with bat guano. In some cases, where these caves are in limestone, the nitrate occurs in the form of calcium nitrate, which was probably produced by the oxidation of the nitrogenous materials of the bat guano and the subsequent action of these oxidized products on the limestone. As caves in limestone are very common, the occurrence of calcium nitrate is frequently observed. In the old days nitrate was also made artificially from organic refuse in what were known as niter heaps. These produced mostly calcium nitrate, which was then converted to potassium nitrate. The nitrates in the soils of India and in the niter heaps were derived from nitrogenous animal matter, just as the cave nitrates were derived from guano, and the process in all these cases was made possible by the agency of certain bacteria already described in this paper (see p. 18).

In California, nitrate deposits occur in the arid region of the southeastern part of the state, in San Bernardino and Inyo counties, and elsewhere. The conditions there are not unlike those of northern Chile, the region consisting of high arid basins bordered by mountain ranges. The nitrate is mostly in the form of sodium nitrate, though some potassium nitrate occurs, and is associated with common salt (sodium chloride) and other saline materials, very much as in Chile. As yet these deposits have not become of much commercial value.

In recent years efforts have been made to obtain nitrogen from the air and to convert it to nitrates or other nitrogen compounds available for commercial purposes. The atmosphere contains nitrogen in the proportion of approximately 79 parts to the 100. This nitrogen, as has long been known, can be oxidized by electrical and other methods and converted to nitrates and other salts of nitrogen. Numerous methods for this operation have been devised, but their discussion is beyond the scope of the present paper, and the reader is referred to the readily accessible literature on the subject for further information.

GLACIATION ON THE NORTH SIDE OF THE WRANGELL MOUNTAINS, ALASKA[1]

STEPHEN R. CAPPS

Since the pioneer trip of Lieutenant Henry T. Allen, in 1885, it has been known that a range of mountains lying north of the Chisana River, and later called Wrangell Mountains,[2] was heavily glaciated. The glacial phenomena of the Copper River basin and the south side of this range have been more or less fully discussed by various writers,[3] and some notes have been published[4] on the occurrence and position of glaciers and of Pleistocene deposits on the north side of this range, and in the White River Valley. During the summer of 1908, it was the writer's privilege to take a trip into the region north of the Wrangell Mountains with a party from the U. S. Geological Survey, in charge of Mr. Fred H. Moffit. The attempt is here made to summarize the glacial conditions of this region. In certain portions not personally visited, the unpublished maps and notes of F. C. Schrader, collected in 1902, have been drawn upon. The names of rivers, mountains, etc., referred to are taken from the topographic maps of the U. S. Geological Survey.[5]

The dominant topographic feature of the region under discussion is the Wrangell Mountains, extending from the Copper River basin in a southeastern direction to Russell Glacier and the headwaters of

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] F. C. Schrader, *20th Ann. Rept.*, U. S. Geological Survey, Part VII, pp. 377, 378.

[3] F. C. Schrader and A. C. Spencer, *Geology and Mining Industry of a Portion of the Copper River District*, Alaska, 1901, p. 30; C. W. Hayes, *Nat. Geog. Mag.*,Vol. IV, 1892; Oscar Rohn, *21st Ann. Rept.*, U. S. Geological Survey, Part II, pp. 399–439; W. C. Mendenhall, "Geology of Central Copper River Region, Alaska," U. S. Geological Survey, *P. P. 41*, 1905.

[4] C. W. Hayes, *op. cit.*; A. H. Brooks, *A Reconnaissance from Pyramid Harbor to Eagle City, etc.*, U. S. Geological Survey, 1901.

[5] *Central Copper River Region, Alaska*, U. S. Geological Survey, 1902; *Headwater Regions of Copper, Nabesna, and Chisana Rivers, Alaska,* U. S. Geological Survey, 1902.

the Nizina River. In this range two peaks, Mount Sanford and Mount Blackburn, rise to heights of more than 16,000 feet. Mount Wrangell, a broad, dome-shaped mass, is 14,000 feet high, and many peaks of the range have elevations of from 12,000 to 13,000 feet. East of the Wrangell Mountains, and separated from them by Skolai Pass, is the northwest end of the St. Elias Range. The highest peak seen was Mount Natazhat, near the international boundary. This prominent mountain has a height of about 13,000 feet. North of the Wrangell Mountains and parallel with them, are the Nutzotin Mountains. The two ranges are separated on the west by the Copper River basin, and on the east by an area of low hills, but between the heads of the Copper and Chisana rivers, the two ranges approach one another without any sharp topographic break. The Nutzotin Mountains reach elevations, in their higher portions, of 8,000 to 10,000 feet. The large rivers are the Copper, which makes a great curve and flows south into the Gulf of Alaska, and the Nabesna, Chisana, and White rivers, all of which join the Yukon drainage.

Pleistocene Geology

The region covered by this report is bordered on the south by the high ranges of the Wrangell and St. Elias mountains. The name "Skolai Mountains" had been applied to a portion of this range, on either side of Skolai Pass. Structurally and physiographically, however, the Wrangell Mountains are continuous with the Skolai Mountains, which in turn are directly continuous with the St. Elias Range to the southeast. As the term Skolai Mountains does not apply to any natural division of this range, it is here omitted.

CENTERS OF GLACIATION

WRANGELL MOUNTAINS

A very important feature of the Wrangell Mountains is the great ice-cap which occupies the crest of the range, and which has its greatest development in the region around Mount Wrangell (Fig. 1). From the periphery of this great feeding-ground valley glaciers extend in all directions down the more important drainage lines. This report is concerned only with those glaciers of this group which extend to the north and northeast. In the Wrangell Mountains,

beyond the edge of the great ice-cap, there are numerous localities where the elevation is sufficient to start small glaciers. Small ice-tongues of this type occur between the Copper and Nabesna glaciers, and in the mountains east of the upper Nabesna River.

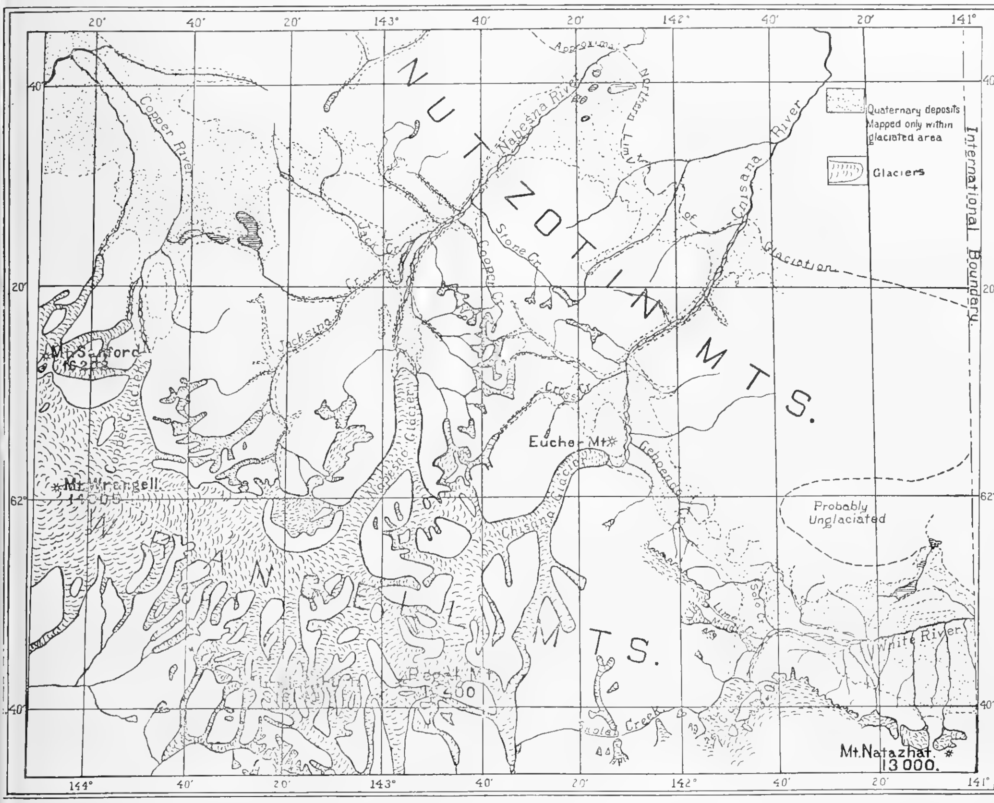

FIG. 1.—Map of a part of the Wrangell and Nutzotin mountains, Alaska. The existing glaciers are shown by the broken lines; the dotted areas show the distribution of the Quaternary deposits. The line of dashes indicates approximately the northern limit to which earlier glaciers reached. Compiled from published and unpublished maps of the U. S. Geological Survey.

ST. ELIAS MOUNTAINS

Second in importance in the region here discussed to the Mount Wrangell distributing center, is the ice-cap which occupies the St. Elias Mountains, south of the White River. Little is known of this ice-field, except along its northern border. As far as can be

seen from the White River Valley, all of the main range which lies west of the international boundary and south of the White River is capped with ice above an elevation of about 7,500 feet. As in the Wrangell Mountains, all of the important valleys which head back into the range are occupied by valley glaciers.

NUTZOTIN MOUNTAINS

A few small glaciers have survived in the more favorably situated valleys of the Nutzotin Mountains between the Chisana River and Suslota Pass. The largest of these is not more than three miles long.

INFLUENCE OF PRESENT GLACIERS UPON THEIR VALLEYS

Erosive effects.—The existing glaciers are now exerting a most important influence upon the shapes of their valleys. By the rasping of their beds with rock fragments held in the moving ice; by freezing to the bed rock and plucking out blocks of it; and by undermining the valley walls and causing the material above to fall down upon the glacier, the ice is enabled to remove great quantities of material from the valleys in which it is confined. The result of this erosion is to be seen in the characteristic shapes of the valleys in which it has been effective. Instead of the usual V shape of stream-cut valleys in rugged, youthful mountains, we find everywhere a broad U-shaped cross-section. The ice tends also to steepen the valley gradient toward the glacier-head, but to reduce it toward the foot of the glacier. In areas from which the ice has retreated, the bedrock often shows well-marked striations, or surfaces which have been smoothed or polished by the grinding. There is also a notable absence of sharp angular surfaces or protrusions of the bedrock, as all such projections have been worn away by the ice.

Effects on valleys below glaciers.—Glaciers also have an important influence upon the topography of the valleys below the ice-edge. All of the material which a glacier carries, either inclosed in the ice, or upon its surface, is ultimately carried toward the terminus and dropped as the ice melts away. It often accumulates as considerable moraine deposits, consisting of a heterogeneous mixture of angular or partly rounded rock fragments with finer clays. Often striae can be found upon the included bowlders.

Since the ice-borne materials are either deposited at the melting edge of a glacier, or beneath the body of the melting portion of the ice, there is always a great deal of running water present. Often streams of large volume flow out from beneath the glacier, but the volume of flow varies seasonably and daily as the temperature rises and falls. At times of rapid melting the streams carry large volumes of water, and are able to handle a great amount of the débris brought down by the ice. The material may be carried for long distances, or much of it may be dropped within a short distance from the glacier. The daily fluctuations in volume of the streams is an important factor in both the transportation and deposition of the débris.

Materials which have been deposited by streams differ notably in structure from those deposited directly by the ice. The water tends to assort the materials, and while the stratification may be very imperfect, the structure is readily distinguishable from that of glacial till.

Both the moraines and the stream-laid gravels form important topographic features in the valleys below the glaciers. The moraines are usually most prominent near the ice-edge, as they are readily cut away and destroyed by the streams. The outwash gravels are often of great extent, and the broad gravel bars with their anastamosing streams cover the valley floors of almost all the glacier-fed drainage lines.

EVIDENCES OF EARLIER AND MORE EXTENSIVE GLACIERS

We have seen that glaciers have an important influence upon the valleys which they occupy, both in determining the shape of the valleys, and in causing the deposition of moraines and gravels. These evidences are definite, and would remain even if the ice should melt and disappear. In the region under discussion there is abundant evidence of this sort, which shows that at no distant geological period the glaciers were of much greater size and extent than they are now. The valleys have been broadened and deepened, and show a marked U shape in cross-section far below the limits of the present ice. Furthermore, the rock surfaces are often striated, and there are unmistakable deposits of glacial till at many points from which the ice has long ago disappeared. In the Nabesna Valley, for example, the ice probably extended 40 or 50 miles to the northeast from the edge

of the present glacier, and spread out upon the plain at the north base of the Nutzotin Mountains. At this time, the glacier was about 100 miles long from its terminus to the top of Mount Wrangell, where it headed. Other glaciers of this region were proportionately greater.

An attempt has been made, based on somewhat incomplete data, to show the northern limits of the glaciers in this region at the time of their maximum extent (Fig. 1). The glaciated area includes all of the Wrangell, Nutzotin, and Skolai mountains. It is probable that at no time were the Nutzotin Mountains entirely ice-covered, but only the highest peaks and ridges projected above the glacier, and the total area of these projecting points was very small.

COPPER RIVER VALLEY

The Copper River heads in a glacier which receives the ice from the north slope of Mount Wrangell and from a part of the east slope of Mount Sanford. Although seen only at a distance by the writer, its general characteristics can be learned from the topographic map. In length this glacier is much inferior to those in the valleys of the Nabesna and Chisana rivers, to the east. It is about 20 miles long from the top of Mount Wrangell to the terminus, and has an area of approximately 140 square miles.

Small glaciers in the Copper drainage.—East of the main ice-body there are three small glaciers which lie high up the rock-wall and fail to send their ice-tongues down to join the main lobe. On the west, West Glacier moves from Mount Sanford down to the main valley, which it reaches three miles below the end of the Copper Glacier. Drop Glacier, still farther to the northwest, is the last ice-tongue of importance within the boundaries of the region under discussion.

Glacio-fluvial deposits.—Below the edge of the mountains the great Copper River basin extends to the north and west. The basin is covered with extensive gravel deposits which contain a great variety of beds ranging from coarse gravels and unassorted glacial till to finely assorted clays and silts. The extension of these beds to the west and south has been discussed by Mendenhall.[1] Toward

[1] *Op. cit.*, pp. 62–72.

their upper end they appear as a broad plain into which the rivers have cut considerable valleys.

Extent of earlier glaciers.—In the Copper River Valley, as in all the valleys of these mountains, the ice has formerly been much more extensive than at present. The mountain just below the glacier was once surrounded, and perhaps entirely covered by the ice. Mendenhall advanced the opinion that the entire Copper River basin was probably at one time occupied by ice.

NABESNA VALLEY

Nabesna Glacier.—The Nabesna Glacier is the great body of ice which occupies the head of the valley of the same name. It receives the ice from a great portion of the north slopes of the Wrangell Mountains, its feeding-ground extending from Mount Wrangell in an east-southeast direction to Mount Regal, a distance of 43 miles. The outlines of the glacier form a complicated dendritic pattern, as about 40 cirques contribute their ice to it. At a point 20 miles northeast of Mount Blackburn the ice is confined within a single valley and forms a lobe a little more than two miles wide. Below this point the glacier is of nearly uniform width, and receives but a single important tributary. It moves from this point northeast and then north to its terminus, a distance of 20 miles. The total length of the glacier, from Mount Wrangell to its lower end is about 55 miles, and its area approximately 400 square miles.

As viewed from the mountain-side, below Nikonda Creek (Fig. 2), the main lobe of the glacier shows a fairly smooth surface and a uniform slope as far as the eye can see. There are no cascades or steep pitches on the surface, although the great branch which comes in from the direction of Mount Regal descends steeply into the main valley. The surface slope of the main lobe is about 50 feet per mile.

Moraines.—A prominent medial moraine follows the center of the glacier for many miles above its lower end. It is flanked closely on either side for a part of its length by narrower parallel moraines. The débris showing on the surface becomes more prominent to the northward, and near the terminus the band-like ridges become so frequent that at its north edge the ice is entirely covered by rock débris, and grades imperceptibly into the terminal moraine.

About one mile above Nikonda Creek a rock island or nunatak stands up through the ice. Its surface is covered with loose material, but is bare of vegetation.

The terminal moraine of this glacier covers the valley floor for about two miles below the ice-edge, except for narrow valleys on the east and west through which the waters of the melting glacier escape to the north. The moraine surface is of very irregular topography,

FIG. 2.—The Nabesna Glacier.

and consists of a succession of hummocks and kettles, many of which contain lakelets. No well-established drainage lines were observed.

The extent of the terminal moraine shows that the glacier is at present retreating. It has been deposited so recently that over most of it no vegetation has as yet obtained a foothold. Along the northern edge there is a low growth of bushes, but no trees of size.

Small glaciers in the Nabesna drainage.—There are a number of small glaciers to be found at the heads of tributaries of the Nabesna, which themselves do not connect with the main glacier, or extend

down to the trunk valley. Of those on the east five drain into Nikonda Creek, nine into Bond Creek, three into Camp Creek (Fig. 3), at least one into Cooper Creek, and three into Stone Creek. From the west, about ten glaciers drain into Jacksina Creek and one into Platinum Creek. Almost all these are cliff glaciers of small area, and are but the remnants of larger bodies of ice which formerly occupied the valleys.

Glacio-fluvial deposits.—The Nabesna Valley, from the terminal moraines to the north base of the Nutzotin Mountains, is floored by

Fig. 3.—Glacier at the head of Notch Creek, and small cliff glaciers on the walls above.

gravel beds. The bars are from one to three miles wide, and the river anastamoses over much of this flat in periods of high water. Although the current is swift, the stream is heavily loaded, and the flat is constantly being built up by the outwash from the glacier.

The stream fluctuates daily in volume in the summer season. It is a well-recognized fact by travelers in this region that streams which are not fordable in the afternoons of warm days can be easily crossed on cold days, or in the early morning before the melting ice has swelled the current. In times of high water the main channels may locally deepen their beds. Large bowlders are moved, and can often be heard bumping along the bottoms of the streams. At the same time, the heavily burdened waters may be depositing rapidly in the shallower and more sluggish channels. In the night time,

and on cold days, deposition is general throughout all the stream-courses.

The character of the valley gravels changes notably as one proceeds down stream. Near the glacier the gravels are generally coarse. Farther down they become progressively finer and finer, and bars of small gravel and sand take the place of the cobbles so abundant above.

All of the larger tributaries of the Nabesna River, including Nikonda, Bond, Cooper, and Stone creeks from the east, and Monte Cristo, Jacksina, Jack, and Platinum creeks from the west, have gravel bars similar in origin to those in the main Nabesna Valley, but smaller in size.

Terraces.—The conditions for the deposition of the gravel beds in the Nabesna Valley have not been uniform since the withdrawal of the greater glacier, and it is not to be expected that they would have been. The retreat of the ice probably consisted of many withdrawals interrupted by halts, or even by slight readvances, and from time to time the quantity of water, as well as the abundance and variety of the materials to be transported would have varied. At times of ice-advance the streams were supplied with an excessive amount of detritus, and would therefore have built up their beds with great rapidity. Later, with a comparative scarceness of gravels to be carried, the streams would have been able to entrench themselves in the gravel bars already formed. That some such conditions actually did exist is shown by the terraces of stream-laid gravels which are now to be seen at various places along the Nabesna Valley. These terraces have their best development between Bond Creek and California Creek. At their upstream end they reach an elevation of about 200 feet above the river, but slope gradually downward to the north, and near Bond Creek merge with the gravel bars which the river is now building.

Just south of California Creek, the plain-like surface of the terraces is broken by a number of low, irregular hillocks, composed of glacial till. These indicate that the terrace gravels were here laid down around and on top of a terminal moraine during the retreat of the glacier. The stream has now cut its channel 200 feet into these gravel beds.

For some distance above Camp Creek, and between Copper and Stone creeks, there are gravel terraces which stand 30 to 50 feet above the stream.

Extent of earlier glaciers.—As shown in Fig. 1, the Nabesna Glacier was formerly of much greater size than it is at present. The glaciers from the Wrangell Mountains, moving northward, were unable to override the opposing Nutzotin Mountains, but sent their ice across this range through the two great troughs through which the Nabesna and Chisana rivers now flow. In the Nabesna Valley the ice extended to the north base of the Nutzotin Mountains, and there spread out into a broad, spatulate lobe. The outlines of this lobe have not been traced, but there is reason to believe that its northern edge was 40 or 50 miles below the existing ice-edge. The ice filled the valley to a depth of 2,000 to 3,000 feet, and its erosive power was enormous. It truncated the lower ends of the rock spurs on either side of the valley and developed the broad U-shaped trough through which the river now flows. There is a notable absence of craggy outcrops and of ridge-like spurs along the valley-sides.

At the time of the maximum ice-advance each tributary valley in the Wrangell and Nutzotin mountains sent down a glacier to join the main lobe so that only the highest peaks and crests of the mountains projected above the ice. With a change in climatic conditions came a gradual contraction of the glaciated area. The ice in the large trunk valley slowly melted back and left separate the small glaciers which occupied the side gulches. These in turn retreated toward their heads, and although many of them have now disappeared entirely, their former presence is shown by the U shape of the stream-troughs, and by the moraines which the ice left.

CHISANA VALLEY

Chisana Glacier.—The Chisana Glacier, locally called the Shushana, lies on the northeast slope of the Wrangell Mountains, between the Nabesna and White valleys. Its heads reach westward to the Nabesna divide, and in many of the cirques the ice is continuous across the divide with the easternmost heads of the Nabesna. To the south the ice is continuous over the divide with the Rohn and Nizina glaciers on the south slope of the mountains (Fig. 4). There

are but 14 tributary cirques, as compared with 40 to the Nabesna Glacier, and the total area of ice is about 135 square miles. Its length, from the terminus to the Chisana-Rohn divide, is 30 miles.

FIG. 4.—The summit of the Chisana-Rohn divide. Photograph by Rohn, 1899.

A fine view of the glacier can be obtained from Euchre Mountain, at its lower end. The glacier, which for about twelve miles above Euchre Mountain consists of a single lobe, swings in a broad curve from a north to an eastern direction. Its surface, so far as could be

FIG. 5.—Lower end of the Chisana Glacier. Photograph by Rohn, 1899.

seen, was free from sharp breaks in gradient and from prominent crevasses (Fig. 5).

Moraines.—A prominent medial moraine belt, lying somewhat west of the center of the glacier, appears on the surface far above the great bend of the ice. At the bend it has a curious zig-zag shape,

and extends to the ice-edge above Euchre Mountain. It is the only continuous belt of moraine to be seen from this mountain.

There is an almost complete absence of distinct terminal moraine deposits, and it is concluded that the glacier is retreating. If this is the case, however, the ice-movement must be very slow, for a comparison of the photographs taken by Rohn[1] in 1899 with those taken by the writer nine years later show surprisingly little change in the aspect of the glacier. The moraines appear the same, and there are only slight changes in the courses of the streams below the ice-edge. At one place a slight recession has taken place in the edge of the glacier.

Small glaciers in the Chisana drainage basin.—There are a number of small glaciers which drain into the Chisana Valley. On the east several little ice-lobes project down from the ice-field which caps the mountains southeast of Euchre Mountain. These form the heads of Bow and Gehoenda creeks. On the west, four small glaciers drain into Cross Creek, two from the Wrangell Mountains (Fig. 1), and five from the Nutzotin Mountains into Notch Creek. Mount Allen supports two little ice-tongues which drain into the Chisana below the mouth of Cross Creek.

Glacio-fluvial deposits.—The valley below Euchre Mountain contains broad gravel bars built up by the streams from the glacier. The stream-laid deposits differ notably, however, from those found immediately below the Nabesna Glacier. Here coarse gravel is the exception, and as far north as the mouths of Cross (Copper) and Chavolda creeks, the bars are largely composed of fine gravels and sands. The valley is wide and the stream breaks up into a multitude of channels. On the afternoons of warm days, these channels were observed to overflow and join until much of the wide flat was covered by a thin sheet of water.

Below the mouth of Cross Creek, the gravels become much coarser, as this creek discharges coarse gravels. The valley through the Nutzotin Mountains is a narrow U-shaped gorge, and the waters flow in a few large channels. Through the gorge there is shown the usual succession of coarse gravels above, becoming progressively finer down stream.

[1] Oscar Rohn, *21st Ann. Rept.*, U. S. Geological Survey, Part II, Pl. LV.

All of the larger tributaries of the Chisana River, including Bow, Gehoenda, Chathenda, and Chavolda creeks from the east and Cross Creek from the west, have valleys floored with gravels, and most of these streams have developed fans where their gravel bars coalesce with those of the main valley.

Terraces.—Conspicuous terrace deposits occur at several points along the valleys of the Chisana and its tributaries. East of Euchre Mountain, and including the lower portions of Bow, Gehoenda, and Chathenda creek valleys, there is a broad area of gravel deposits into which these streams have entrenched themselves. The area now covered by these gravels was formerly occupied by the Chisana Glacier. As the glacier decreased in size the ice-edge gradually shrank back toward the west and exposed this region, while it was still of sufficient thickness in the main Chisana Valley to form an obstruction to the streams from the east. Under these conditions the creeks rapidly built up their valleys with alluvial material. It is even possible that temporary lakes were formed behind the ice-dam. An exposure along Gehoenda Creek for several miles above its mouth shows fine, stratified gravels and silts, interbedded with coarser materials. The rather perfect stratification of the finer materials suggests a lacustrine origin for these beds.

On Notch Creek there are terrace gravels on both sides of the stream. They occur intermittently from the base of the mountains near the head of the creek to its mouth, and in places the stream-cut bluff shows a section of 150 feet of the coarse, rudely stratified gravels with interbedded lenses of sand. They are evidently stream-laid and may have been deposited synchronously with the terraces in the Nabesna Valley described above.

About ten miles below the mouth of Chavolda Creek, on the northwest side of the Chisana River, there is a good exposure of terrace gravels. In the bank about 60 feet high the lower 40 feet are exposed. The section (Fig. 6) shows 15 feet of coarse gravel at the base, with occasional bowlders 18 inches in diameter. Above this is 25 feet of fine, well-stratified gravel with pebbles five inches or less in diameter. The terraces were probably built contemporaneously with those in Notch Creek.

Extent of earlier glaciers.—As is the case in other valleys of this

region, the Chisana trough has very evidently been occupied at no very remote period by a glacier of much greater extent than the present one. It pushed from the Wrangell Mountains northeast through the Nutzotin Mountains to their north base, and was very deep throughout the valley. On Euchre Mountain there are moraines and erratic bowlders up to the 6,600-foot level, or 2,500 feet above the terminus of the present glacier, and in the low col west of this mountain there must have been at least 1,200 feet of ice which moved northward. Euchre Mountain at that time was an island standing about 1,000 feet above the surface of the surrounding glacier. East and northeast of Euchre Mountain the ice was not confined by steep valley-walls, and doubtless spread out into a wide lobe at this place. Below Chavolda and Cross creeks it was again compressed to a narrow tongue in the canyon-like valley through the Nutzotin Mountains, and probably again deployed on the plain to the north of this range.

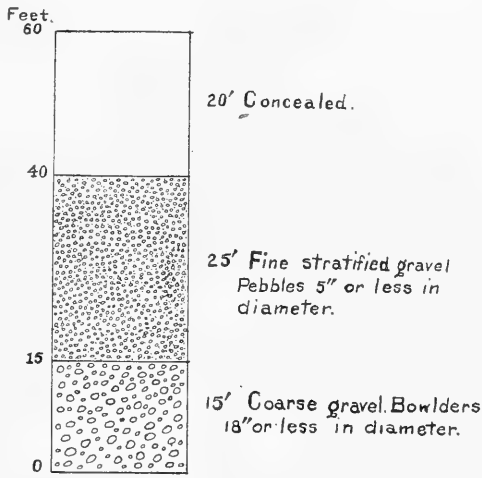

FIG. 6.—Section of gravel terrace on the Chisana River, 10 miles below the mouth of Chavolda Creek.

At the climax of this glacial period, each tributary valley of the Chisana, both in the Wrangell and Nutzotin mountains, was occupied by a glacier which joined the body of ice in the main valley. It is probable that the whole mountainous area had much the same appearance at that time as that shown by the higher parts of the Wrangell Mountains now (see Fig. 4).

Since the retreat of the ice to its present position, the greater number of tributary valleys have been deglaciated; and only the higher and more favorably situated summits have perennial ice upon their flanks.

In the canyon of the Chisana, between the mouth of Chavolda Creek and the north base of the mountains, the rock valley walls show in many places one or more smooth, rounded benches, due to glacial erosion. The benches are inconspicuous when near at hand, but are plainly discernible from a distance. They can rarely be followed for more than a mile or so, and it was impossible, in the short time available, to correlate the benches in different parts of the canyon.

WHITE VALLEY

Russell Glacier.—The head of the White River is occupied by a body of ice which was first crossed in 1891, by C. W. Hayes, and was named Russell Glacier[1] by him. The pass over this glacier he named Skolai Pass, and from this fact the name Skolai Glacier is commonly used in the region. The feeding-ground from which this ice-field moved is located in the high mountains east and southeast of Skolai Pass, and as these mountains have never been accurately mapped, no data is available for determining the area and length of the glacier.

As stated above, all the valleys which supply ice to the main glacier head to the east and south. The northernmost of these, at the head of Moraine Creek, joins the main lobe near its terminus. The tributary valley divides, a short distance above its mouth, into two cirques which head in the snow-capped mountains to the east. South of Moraine Creek there are four important tributary glaciers, all of which have their sources in the high, snow-capped, unexplored mountains (Fig. 7).

The main lobe of ice in the head of the White Valley is between 6 and 7 miles long, and about 2½ miles wide, and most of the ice moves in a northeast direction. A small crescentic lobe, however, moves westward into the head of Skolai Creek.

The surface of Russell Glacier is for the most part much crevassed and difficult to cross. The lower two or three miles of ice are moraine-covered, and have been melted into rugged surface shapes in which the ice can be seen only where the slopes are too steep to hold the moraine material. Numerous lakelets were seen to occupy basins in the ice (Fig. 8). Above the moraine-covered portion of the glacier

[1] *Nat. Geog. Mag.*, Vol. IV, 1892, p. 152.

there is a belt, near the west edge, in which the surface is free from

FIG. 7.—View showing surface character of the upper portion of Russell Glacier.

débris and level enough to make travel easy. Here there are few crevasses for a distance of perhaps three miles. As the lobe which

FIG. 8.—A lake in the moraine-covered ice of Russell Glacier.

moves into the valley of Skolai Creek is approached, the ice-surface again becomes broken and irregular, with rugged, moraine-covered

areas and great systems of cracks at right angles to the Skolai Creek Valley (Fig. 9). There is little terminal moraine bordering this lobe, and Skolai Creek has a flat bar composed for the most part of silty quick-sands.

Moraines.—A number of belts of medial moraine lie upon the surface of this glacier. The most important one extends continuously down the center of the main ice-lobe. Other less conspicuous lines occur below the junction-points of the various heads.

The terminal moraine forms a great lobe at the head of White River. It was impossible to determine the line where the glacier ice ends and the terminal moraine begins, as the two blend imperceptibly. A considerable area of the ice is moraine-covered, and there is doubtless much ice inclosed in the moraine deposits. The moraine is a confused jumble of fine material and rock fragments of all sizes and shapes. Drainage lines have been developed only along its edges.

Russell Glacier seems to be retreating. The terminal moraine is new and barren of vegetation, and the ice above it is much decayed. The comparatively recent age of the moraine is also attested by a large admixture of the volcanic ash which is of widespread occurrence in this region, and which lies as a white covering on the lower spurs of the ridges north of Mount Natazhat.

Small glaciers in the White River basin.—In some of the tributary valleys to the west and south of the White River there are small glaciers, the remnants of ice-tongues which formerly reached down to the main valley. In Middle Fork and Lime creeks to the west, the valley-heads contain glaciers, and smaller ice-fields lie on favorable places along their walls. Wiley Creek, to the east of the great terminal moraine, has an ice-field at its head. All the small streams which join the White River between the great bend and Holmes Creek, head in lobes of the ice-cap which covers the range. Holmes Creek has a deep valley which extends for some distance back into the mountains, and a glacier occupies this canyon to its mouth. Mount Natazhat and the great ridge extending west from it, form a series of magnificent cirques, with ice-tongues which extend to the foot of the mountains (Fig. 10).

Glacio-fluvial deposits.—The gravel deposits now being laid down

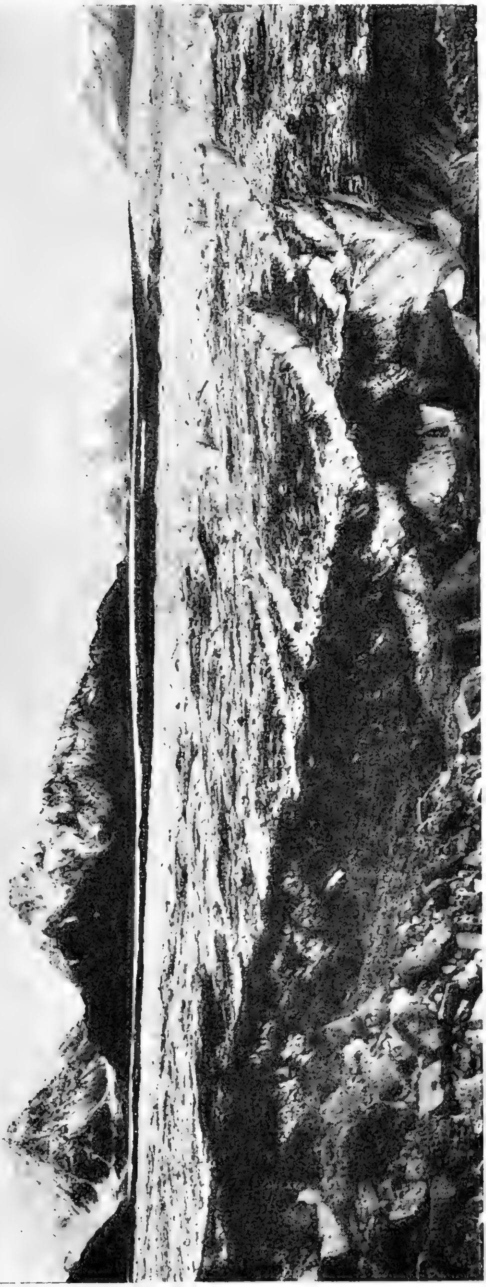

Fig. 9.—View toward the head of Russell Glacier. A medial moraine appears in the immediate foreground, and another in the middle distance.

in that part of the White River Valley which lies west of the international boundary, are very extensive. The area of deposition varies in width from about two miles, just below the glacier, to about nine miles, south of Mount Natazhat. For the first ten miles below the glacier the valley is flat from side to side and is for the most part bare of vegetation. East of Ping Pong Mountain, the White River itself occupies only a narrow valley close to the base of a rock ridge. The remainder of the broad valley to the south slopes upward toward the mountains, and consists of a compound alluvial fan built up by

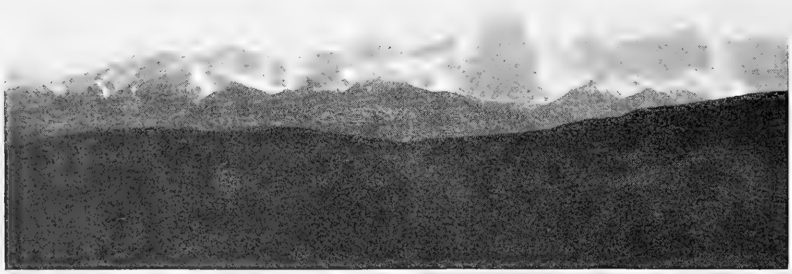

FIG. 10.—Mount Natazhat, and the great cirques on its flanks. Each of these cirques is occupied by a glacier. Photograph by F. H. Moffit.

the tributaries from the south. This fan is heavily timbered except for narrow belts along the streams. The present course of the White River has been determined by this alluvial fan which has crowded the river north against the base of Ping Pong Mountain.

Fig. 11 is a diagrammatic cross-section of the White Valley, five miles west of the boundary. If we can assume that the wide valley north of Mount Natazhat was eroded by the great glacier to an average depth equal to the present level of the White River (*a*), then the valley filling of alluvial gravel must be more than 400 feet thick in the center of the old valley (*b*). Since the White River was nowhere observed to have cut its valley down to bedrock, and since the bedrock level at (*b*) is probably lower than at (*a*), the thickness of the gravels in the deepest portions of the old valley may greatly exceed 400 feet.

Aside from the fan-building streams from the south, the valleys of North Fork, Lime Creek, Middle Fork, and Wiley Creek all have gravel bars extending upstream for some distance above their junctions with the White River gravels.

Terraces.—In this valley remnants of high terraces were noted only on the north side of the river. For about two miles below the mouth of the Lime Creek Canyon, there is a bench of coarse gravels from 30 to 50 feet high. Farther east, along the south base of the Ping Pong Mountain ridge, the river bluff shows a 50-foot cut. Of this section (Fig. 12), the lower 35 feet are composed of coarse, rudely stratified

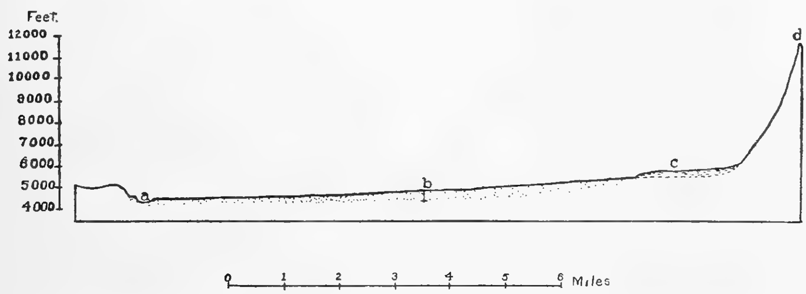

FIG. 11.—A north-south section across the White River Valley, about $5\frac{1}{2}$ miles west of the international boundary. *a*, White River; *b*, alluvial fan; *c*, small glacier; *d*, peak two miles west of Mount Natazhat.

gravels. Above this are 15 feet of blue glacial till. Locally the gravel beds immediately below the till are much distorted and crumpled, showing that after the gravels were deposited, the glacier advanced over them, disturbing their bedding and depositing a sheet of till. There may be gravels of the same age south of the White River, but the present tributaries from the mountains to the south are so actively engaged in building alluvial fans that any remnants of higher terrace gravels which might have existed on that side of the river have been cut away, or covered up by more recent deposits.

Extent of earlier glacier.—At the time of the great ice-advance, a glacier, of which Russell Glacier is the surviving remnant, moved eastward along the White Valley and extended well across the international boundary. At the boundary it had a width of more than 10 miles, and its surface stood more than 1,600 feet above the present level of the White River at this place, for there are evidences of glacia-

tion at the top of a 1,600-foot hill just east of the boundary. The glacier also covered the ridge of which Ping Pong Mountain is the west end. Unlike the ice-fields which occupied the Nabesna and Chisana valleys, this one was not fed by tributaries from both sides of its valley, but only from the valleys of the high mountains to the south and west.

The severity of the glacial erosion upon the valley walls is well shown by the abrupt triangular faces of the spurs opposite the mouths of North Fork and Solo creeks.

Solo Creek gravels.—North and west of Solo Creek there is a broad, flat area covered with outwash gravels, which were laid down under much the same conditions as were those east of the Chisana Glacier. Here the receding ice in the White River Valley left bare a broad area which normally drained into the White River. The drainage was here impeded by the valley glacier, which must have occupied the valley long after the higher area to the north was deglaciated. During this period of obstructed drainage extensive gravel beds were laid down, which abutted against the ice to the south, and spread northward and filled the old drainage channels. The filling went on to such an extent that some of the streams found a lower outlet to the northeast, and still flow in that direction. Solo Creek has now cut a considerable gorge through the gravels and into the underlying rock, and is gradually recapturing for the head of the White River the drainage lost during early glacial times.

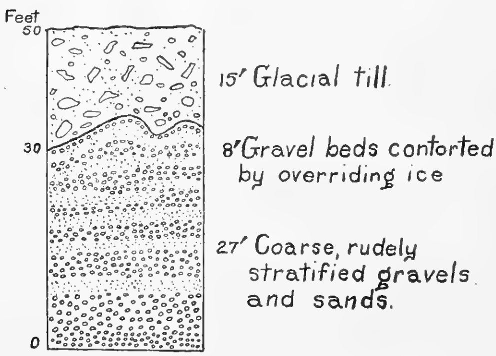

FIG. 12.—Section of terrace on White River, showing glacial till above, and gravels below. The upper portion of the gravel beds has been distorted by the over-riding ice.

Ptarmigan Lake gravels.—Between North Fork and Ping Pong Mountain, a broad flat has a gravel covering due to the same causes as those which brought about the deposition of the Solo Creek gravels.

Ptarmigan Lake would normally drain into the White River to the south, but its waters found an outlet by way of Beaver Creek at the time the glacial ice in the White River Valley formed a barrier to drainage in that direction. The development of its gulch by Cache Creek may some day result in the recapture of this drainage, as the gulch is now being rapidly deepened headward.

GLACIERS IN SKOLAI CREEK DRAINAGE

Skolai Creek is the stream which flows eastward from a lobe of Russell Glacier, and after traversing a narrow, deep valley for about 17 miles, is impounded to form a lake at the edge of the Nizina

FIG. 13.—Terminus of Frederika Glacier. This glacier terminated, in 1891, in an ice-cliff 250 feet high. Photograph by F. H. Moffit.

Glacier, and has its outlet beneath this ice-dam. From the north a single ice-lobe, Frederika Glacier, drains into Skolai Creek. C. W. Hayes, who saw this glacier in 1891, says of it,

> The glacier terminates in a nearly vertical ice cliff stretching across the lateral valley a mile in length, and about 250 feet high. Its surface is free from moraine, but is extremely rough and broken, wholly unlike the surface of stagnant ice at the end of a retreating glacier.[1]

He also mentions this glacier as being the only one seen that summer which appeared to be actively advancing. As seen by the writer, the

[1] *Nat. Geog. Mag.*, Vol. IV, 1892, p. 133.

glacier now terminates about one mile north of Skolai Creek. Its surface is remarkably smooth and slopes down evenly to a thin edge in front (Fig. 13). It was found to be easier to take a pack train across this low ice-tongue than to ford the torrential stream below.

From the south, a number of glaciers drain into this valley. About three miles below Russell Glacier a moraine-covered ice-lobe pushes down to the valley and dams the stream so that a considerable lake is

FIG. 14.—An advancing glacier in Skolai Creek Valley, opposite Frederika Glacier.

formed. Opposite the mouth of Frederika Creek, a beautiful cascade glacier tumbles out from between castellated peaks and pushes northward to Skolai Creek (Fig. 14). It is evidently an advancing glacier now, and was the only one seen during the season which seemed to be advancing. The writer is unable to account for the singular change in conditions which has caused Frederika Glacier, which 17 years ago was advancing, to retreat, and at the same time has brought about the advance of a glacier just to the south, which in 1891 was retreating.

Below Frederika Creek there are several small cliff glaciers on the south valley-wall. At their heads the rock rises almost perpendicularly for a thousand feet or more. On a warm afternoon, great blocks of ice from above could be seen to break off and fall down this cliff with a great noise. The ice was broken to fine fragments before it reached a lodgment below.

THE CALCULATION OF THE NORM IN IGNEOUS ROCKS

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In presenting to successive classes of students in petrography the method of calculating the norm for igneous rocks under the quantitative classification of Cross, Iddings, Pirsson, and Washington, the writer has found such a selection of calculated analyses as is here given, accompanied by discussion, of great service. For practice in calculation the collection of analyses with their norms by Dr. H. S. Washington given in *Professional Papers 14 and 28* of the U. S. Geological Survey is invaluable. Of the calculated analyses which follow, all but two are taken from *Professional Paper 14*. By using the tables given at the end of the *Quantitative Classification of Igneous Rocks*[1] the arithmetical work in calculating the norms is very greatly lessened. The first set of tables, prepared by Professor J. F. Kemp and originally published in the *School of Mines Quarterly*,[2] gives the molecular proportions for the percentage figures of the several oxides recorded in rock analyses. The second set of tables in the *Quantitative Classification of Igneous Rocks* gives the percentage weights for various proportions of molecules of the standard rock-making minerals. The molecular proportions may be calculated by dividing the percentage figures for each oxide by the molecular weight of the oxide. Thus for 65.70 per cent. silica the molecular proportion is 1.095, the molecular weight of SiO_2 being 60. The molecular proportion for 15.40 per cent. soda is .248, the molecular weight of Na_2O being 62. As a preliminary step in the calculation of an analysis the molecular proportions for each oxide must be looked up in the tables. Small amounts of MnO (.001 to .005), and NiO are to be used as FeO;

[1] Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks* (Chicago: The University of Chicago Press, 1903), pp. 237–59.

[2] J. F. Kemp, "The Recalculation of the Chemical Analyses of Rocks," *School of Mines Quarterly*, XXVII, 75–88.

and in the same manner small amounts of BaO and SrO are to be added in with the CaO. If Cr_2O_3 does not amount to .002 it is to be added in with Fe_2O_3. For the calculation of a rock analysis we then start with the molecular proportions of the ten oxides SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, K_2O, TiO_2, and P_2O_5, which are contained in nearly every rock, and we may also have present ZrO_2, SO_3, Cl, F, and CO_2, besides H_2O; and, in smaller amounts, MnO and NiO to be summed in with FeO; BaO and SrO, to be added to CaO; and Cr_2O_3 which is to be counted as Fe_2O_3. ZrO_2, Cr_2O_3 in amount more than .002, TiO_2, P_2O_5, SO_3, Cl, CO_2, and F, when they are present, are first calculated as minor inflexible molecules. Their calculation as zircon, chromite, ilmenite, apatite, noselite, sodalite, calcite, and fluorite presents no difficulty, for the method of procedure is always the same. The eight oxides SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, and K_2O are of much greater importance in the calculation of the norm, for any one of these oxides in a given analysis is disposed of with regard to the relative quantities of all the others. The difficulty in presenting to the student the method of procedure in its entirety lies in the fact that a rather long series of considerations is to be put before him at the very outset. The aim of the writer in the present paper is to develop little by little with the aid of examples and discussions the condensed, precise statement of the authors of the *Quantitative Classification of Igneous Rocks*, pp. 188–96.

The simplest cases are those in which SiO_2 and Al_2O_3 are present in relatively large amounts so that they meet all claims upon them and are not exhausted. Al_2O_3 remaining over is corundum, and SiO_2 remaining over after all the allotments is quartz. With SiO_2 present in abundance Al_2O_3 may meet all the claims of K_2O, Na_2O, and CaO upon it; or it may satisfy K_2O, Na_2O, and part of the CaO. Again it may satisfy only K_2O and part of the Na_2O; or, rarely, only part of the K_2O. So the treatment varies.

The norm minerals of the two groups, which figure in the calculation, with the abbreviations for their names, and their formulas, are as follows. The table is intended to set forth the relative importance of their several rôles in the norm.

I. SALIC GROUP

Dominantly Siliceous and Aluminous

A.	Quartz	SiO_2	Q.
	Corundum	Al_2O_3	C.
	Orthoclase	$K_2O.Al_2O_3.6SiO_2$	or.
	Albite	$Na_2O.Al_2O_3.6SiO_2$	ab.
	Anorthite	$CaO.Al_2O_3.2SiO_2$	an.
	Leucite	$K_2O.Al_2O_3.4SiO_2$	lc.
	Nephelite	$Na_2O.Al_2O_3.2SiO_2$	ne.
	Kaliophilite	$K_2O.Al_2O_3.2SiO_2$	kp.
B.	Minor inflexible molecules		
	Sodalite	$3(Na_2O.Al_2O_3.2SiO_2).2NaCl$	so.
	Noselite	$2(Na_2O.Al_2O_3.2SiO_2).\ Na_2SO_4$	no.
	Zircon	$ZrO_2.SiO_2$	Z.

Of the salic minerals kaliophilite is very rare, while sodalite, noselite, and zircon are much less rare but still unusual. (See note at end of paper on the substitution of halite, NaCl [Hl], and thenardite [Th], Na_2SO_4, for sodalite and noselite, respectively, among the salic minerals.)

II. FEMIC GROUP

A.	Diopside	$CaO.(MgFe)O.2SiO_2$	di.
	Hypersthene	$(MgFe)O.SiO_2$	hy.
	Olivine	$2(MgFe)O.SiO_2$	ol.
	Acmite	$Na_2O.Fe_2O_3.4SiO_2$	ac.
	Sodium metasilicate	$Na_2O.SiO_2$	ns.
	Potassium metasilicate	$K_2O.SiO_2$	ks.
	Wollastonite	$CaO.SiO_2$	wo.
	Ackermanite	$4CaO.3SiO_2$	am.
B.	Minor inflexible molecules		
	Magnetite	$Fe_2O_3.FeO$	mt.
	Ilmenite	$FeO.TiO_2$	il.
	Chromite	$FeO.Cr_2O_3$	cm.
	Hematite	Fe_2O_3	hm.
	Titanite	$CaO.TiO_2.SiO_2$	tn.
	Perofskite	$CaO.TiO_2$	pf.
	Rutile	TiO_2	ru.
	Apatite	$3CaO.P_2O_5.\ \frac{CaCl_2}{3}$ or $3CaO.P_2O_5.\ \frac{CaF_2}{3}$	ap.
	Fluorite	CaF_2	ft.
	Calcite	$CaO.CO_2$	cc.
	Pyrite	FeS_2	pr.

Of the minor inflexible molecules in the femic group magnetite, ilmenite, and apatite are very common. The others occur occasionally.

Among the femic minerals diopside, hypersthene, and olivine appear very often in the norm, acmite and wollastonite are not unusual, while ackermanite, potash metasilicate, and soda metasilicate are rare. Among the minor inflexible mineral molecules magnetite, ilmenite, and apatite commonly appear; hematite, titanite, perofskite, fluorite, and pyrite are not infrequently met with; and chromite, rutile, and calcite are rare.

The minor inflexible molecules, with the exception of magnetite and hematite, will not be considered at the outset. They are not present in the first eight of the series of calculated analyses, but were they present they would claim attention in the first place. Their calculation is simple, but the form of presentation gains in clearness by bringing them in only after the main features of the calculation have been dealt with. The key to the disposal to be made of the important oxides SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, and K_2O lies in the relative affinities of K_2O, Na_2O, CaO, MgO, FeO, and Fe_2O_3, for SiO_2 and Al_2O_3. The point of prime importance is the amount of the two oxides SiO_2 and Al_2O_3. In the simpler cases K_2O, Na_2O, and CaO are to be allotted to Al_2O_3 and SiO_2 in the right proportions for the formation of the feldspars. K_2O has the strongest affinity for Al_2O_3 and SiO_2. It therefore has the first claim, and, after it has taken its quota of these oxides, Na_2O, with the next strongest affinity for them, receives its quota. Lastly CaO with an affinity less than the others is to be satisfied. The oxides MgO and FeO do not unite with both Al_2O_3 and SiO_2 at the same time in the normative minerals. They combine with SiO_2 alone to form hypersthene and olivine, or with CaO and SiO_2 to form diopside.

In Analysis A the simplest possible case is given. SiO_2 and Al_2O_3 are abundant, occurring in sufficient amounts to answer every claim of K_2O, Na_2O, and CaO upon them. Al_2O_3 remaining over is corundum, and SiO_2 remaining over is quartz. TiO_2 and P_2O_5 are not present, and no other elements occur which should be calculated as the minor inflexible mineral molecules. Fe_2O_3, FeO, and MgO not being present, there is nothing to be allotted for femic minerals.

In accordance with its formula $K_2O.Al_2O_3.6SiO_2$, in the proportions 1:1:6, for orthoclase, K_2O, 53, takes 53 Al_2O_3 and six times as much SiO_2. In the same way albite, $Na_2O.Al_2O_3.6SiO_2$, in the proportions 1:1:6, with Na_2O, 60, takes 60 molecular-proportion units of Al_2O_3 and 6×60 of SiO_2. Anorthite, $CaO.Al_2O_3.2SiO_2$, in the proportions 1:1:2, is made with 20 CaO, 20 Al_2O_3, and 40 SiO_2. Of Al_2O_3, 3 molecular-proportion units are left for corundum. Of SiO_2, 557 molecular-proportion units are left to form quartz. The percentage weights for the calculated minerals have been obtained from the second set of tables, pages 247–59, by looking up for orthoclase (or), the amount of K_2O, 53; for albite (ab), the amount of

ANALYSIS A

TOSCANOSE (APLITE). *Professional Paper 14*, p. 172, No. 122

Dargo, Victoria, Australia

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Sum	
Percentage	76.48	13.94	Trace	None	0.01	1.08	3.70	4.90	1.01	101.12	
Molecular Proportions	1.275	.136				.020	.060	.053	Salic Minerals		Femic Minerals
	318	53						53	or	29.5	
	360	60					60		ab	31.4	
	40	20				20			an	5.6	
		3							C	.3	
	557								Q	33.4	
	NOTE.—or .053×556=29.468 written as 29.5 ab .060×524=31.440 written as 31.4 an .020×278= 5.560 written as 5.6 C .003×102= .306 written as .3 Q .557× 60=33.420 written as 33.4								Sal. H_2O Sum	100.2 1.01 101.21	

Na_2O, 60; for anorthite (an), the amount of CaO, 20; for corundum (C), the amount of Al_2O_3, 3. To get quartz we multiply the amount of SiO_2 left over for it (557), by 60, the molecular weight of quartz. With abundant silica then and with Al_2O_3 greater than K_2O+Na_2O+CaO we make orthoclase, albite, anorthite, corundum with extra Al_2O_3, and quartz with extra SiO_2.

The sum of the percentage figures of the analysis, H_2O being 1.01, is 101.12. The sum of the calculated minerals in the norm with H_2O added in is 101.21, and for every calculated analysis these two should correspond as closely as 1 per cent. or 2 per cent. The correspondence cannot be numerically absolute, but it gives us a valuable check on the correctness of the calculation.

In Analysis B we have the same condition, except that FeO and Fe_2O_3 are both present. After the allotment for the feldspars has been made, and Al_2O_3 remaining over has been given to corundum (C), Fe_2O_3 and FeO, in the proportion 1:1, are allotted to magnetite (mt), and silica remaining over is quartz (Q).

ANALYSIS B

Tehamose (Quartz Porphyry). *Professional Paper 14*, p. 132, No. 10
Tamaya, Chile

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Sum	
Percentage	75.93	13.26	1.47	0.68	None	1.11	3.13	3.19	0.44	99.72	
Molecular Proportions	1.266	.130	.009	.010		.020	.050	.034	Salic Minerals		Femic Minerals
	204	34						34	or	18.9	
	300	50					50		ab	26.2	
	40	20				20			an	5.6	
		26							C	2.7	
			9	9							mt 2.1
	722								Q	43.3	
	Note.—1 FeO neglected.								Sal.	96.7	Fem. 2.1
									Fem.	2.1	
									H_2O	.44	
									Sum	99.24	

The calculation of Analysis C is like the preceding one in its allotments for orthoclase (or), albite (ab), anorthite (an), corundum (C), and magnetite (mt). Then there remain over, besides SiO_2, 2 molecular-proportion units of MgO, and 15 of FeO. These are allotted to hypersthene (hy), $(MgFe)O.SiO_2$, in the proportion $(MgFe)O:SiO_2$ as 1:1. MgO and FeO are used in hypersthene in the ratio in which they happen to stand when this mineral comes to be made. Here the ratio is 2:15. In later analyses MgO and FeO will be introduced into the calculations in the minerals diopside (di), and olivine (ol), as well as in hypersthene. When all three or any two of them are to be made MgO and FeO are to stand in all of them in the same proportion in which they were used in the first of these minerals calculated at the time. In Analysis C it will be noted that hypersthene is the sum of two parts, $MgO.SiO_2$ and $FeO.SiO_2$, each of which is to be found separately. $FeO.SiO_2$ may be looked up in the table on p. 254. $MgO.SiO_2$ is equal to 100 times the amount of MgO. These findings are added together for hypersthene.

ANALYSIS C

ALASKASE (RHYOLITE). *Professional Paper 14*, p. 130, No. 1

Madison Plateau, Yellowstone National Park

Percentage	SiO_2 75.19	Al_2O_3 13.77	Fe_2O_3 0.61	FeO 1.37	MgO 0.09	CaO 0.68	Na_2O 3.83	K_2O 3.33	H_2O 0.65	Sum 99.83		
Molecular Proportions	1.253	.135	.004	.019	.002	.012	.061	.035	Salic Minerals		Femic Minerals	
	210	35						35	or	19.5		
	366	61					61		ab	32.0		
	24	12				12			an	3.3		
		27							C	2.8		
			4	4							mt	.9
	17			15	2						hy	2.2 { $MgO.SiO_2$ .200; $FeO.SiO_2$ 1.98 }
	636								Q	38.2		
									Sal.	95.8	Fem.	3.1
									Fem.	3.1		
									H_2O	.65		
									Sum	99.55		

In Analysis D after the allotment for magnetite (mt), 3 molecular-proportion units of Fe_2O_3 are left over. These go in as hematite (hm). Then MgO, 4, and FeO, 0, are left over. They are used to make a hypersthene free from FeO. In like manner in other analyses hypersthene might be made of $FeO.SiO_2$, the other component $MgO.SiO_2$ not being available.

In analysis E the allotments are made for orthoclase (or), albite (ab), anorthite (an), and magnetite (mt). CaO remaining is allotted, with MgO, FeO, and SiO_2, to diopside (di), $CaO.(MgFe)O.2SiO_2$, the proportions of the constituents by the formula being 1:1:2. MgO and FeO together are equal to CaO, and are used in the proportion in which they are found when the mineral comes to be made. Here the ratio is 36:5, or nearly 7:1. The silica is twice the lime. MgO and FeO remaining are used for hypersthene (hy), still in the same ratio 7:1 (see p. 63, line 11). SiO_2 is allotted by hypersthene in amount equal to MgO+FeO.

It is to be noted that we cannot have diopside and corundum together in the norm.

Analysis F presents the case where K_2O is allotted with Al_2O_3 and SiO_2 to orthoclase (or), and Na_2O is allotted to Al_2O_3 and SiO_2 for albite (ab). Al_2O_3 remaining, 9 units, can satisfy only 9 units of CaO for anorthite (an). Then CaO remaining is allotted to diopside (di), as far as MgO and FeO are available. Of CaO 27 molecular-proportion units are still left. These take an equal amount of SiO_2 for wollastonite (wo), $CaO.SiO_2$, 1:1. It is clear that since MgO and FeO were not present in sufficient amounts to make diopside with all the lime, there remain none of these constituents for hypersthene or olivine. So then with wollastonite there will be no hypersthene or olivine.

We now come to Analysis G, in which with abundant SiO_2, the Al_2O_3 covers K_2O and partly covers Na_2O. Orthoclase (or), is made, and albite (ab), as far as the Al_2O_3 admits of it. Soda, Na_2O, 5 units, left over, there being no Al_2O_3 available for it, takes Fe_2O_3 and SiO_2 for acmite (ac), $Na_2O.Fe_2O_3.4SiO_2$, in the proportions, 1:1:4. It is clear that with acmite there will be no anorthite. After the allotment is made for magnetite (mt), the CaO takes MgO, FeO, and SiO_2 for diopside (di). The remaining MgO and FeO are used

ANALYSIS D

MAGDEBURGOSE (GRANITE). *Professional Paper 14*, p. 124, No. 3
Felch Mountain, Mich.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O				
Percentage	76.10	12.95	0.65	0.09	0.14	0.12	2.36	6.50	H_2O 0.65	Sum 99.65		
Molecular Proportions	1.268	.127	.004	.001	.004	.002	.038	.069	Salic Minerals		Femic Minerals	
	414	69						69	or	38.4		
	228	38					38		ab	19.9		
	4	2				2			an	.6		
		18							C	1.8		
			1	1							mt	.2
			3								hm	.5
	4			0	4						hy	.4 { $MgO.SiO_2$ .400
												$FeO.SiO_2$ .00
	618								Q	37.1		
									Sal.	97.8	Fem. 1.1	
									Fem.	1.1		
									H_2O	.65		
									Sum	99.55		

ANALYSIS E

TOSCANOSE (GRANITE). *Professional Paper 14*, p. 168, No. 92
Riesengebirge, Silesia

Percentage	SiO_2 71.53	Al_2O_3 13.55	Fe_2O_3 1.20	FeO 0.88	MgO 1.45	CaO 3.21	Na_2O 2.61	K_2O 3.95	H_2O 1.75	Sum 100.13				
Molecular Proportions	1.192	.133	.007	.012	.036	.057	.042	.042	Salic Minerals		Femic Minerals			
	252	42						42	or	23.4				
	252	42					42		ab	22.0				
	98	49				49			an	13.6				
			7	7							mt	1.6		
	16			1	7	8					di	1.8	$CaO.SiO_2$	.93
													$MgO.SiO_2$	.700
													$FeO.SiO_2$	.13
	33			4	29						hy	3.4	$MgO.SiO_2$	2.900
													$FeO.SiO_2$	.53
	541								Q	32.5				
									Sal.	91.5	Fem. 6.8			
									Fem.	6.8				
									H_2O	1.75				
									Sum	100.05				

ANALYSIS F

ALASKOSE (GRANITE). *Professional Paper 14*, p. 126, No. 4

Waushara, Wis.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Sum				
Percentage	74.62	10.01	3.85	1.72	0.33	2.43	3.33	3.38	0.24	99.91				
Molecular Proportions	1.244	.098	.024	.024	.008	.044	.053	.036	Salic Minerals		Femic Minerals			
	216	36						36	or	20.0				
	318	53					53		ab	27.8				
	18	9				9			an	2.5				
			24	24							mt	5.6		
													$CaO.SiO_2$	.93
	16			0	8	8					di	1.7	$MgO.SiO_2$	.800
													$FeO.SiO_2$	.00
	27					27					wo	3.1		
	649								Q	39.0				
									Sal.	89.3	Fem.	10.4		
									Fem.	10.4				
									H_2O	.24				
									Sum	99.94				

ANALYSIS G

OMEOSE (LIPARITE). *Professional Paper 14*, at bottom of p. 142, No. 3

Cabo de Gata, Spain

Percentage	SiO_2 71.12	Al_2O_3 13.35	Fe_2O_3 1.37	FeO 1.28	MgO 0.47	CaO 0.32	Na_2O 2.02	K_2O 9.82	HO_2 1.13	Sum 100.88				
Molecular Proportions	1.185	.131	.009	.018	.012	.005	.032	.104	Salic Minerals		Femic Minerals			
	624	104						104	or	57.8				
	162	27					27		ab	14.2				
	20		5				5				ac	2.3		
			4	4							mt	.9		
											di	1.2	$CaO.SiO_2$	.58
	10			3	2	5							$MgO.SiO_2$	.200
													$FeO.SiO_2$	.40
	21			11	10						hy	2.5	$MgO.SiO_2$	1.000
													$FeO.SiO_2$	1.45
	348								Q	20.9				
									Sal.	92.9	Fem.	6.9		
									Fem.	6.9				
									H_2O	1.13				
									Sum	100.93				

for hypersthene (hy), in the same porportion in which they stood for diopside.

Analysis H presents the case where after making orthoclase (or), albite (ab), and acmite (ac), Na_2O still remains over. This is allotted with SiO_2 to form sodium metasilicate (ns), $Na_2O \cdot SiO_2$, 1:1. It is rarely found necessary to introduce sodium metasilicate in this way.

Case I presents the inflexible mineral molecules ilmenite, titanite, apatite, and fluorite. Sodium metasilicate is introduced, and potassium metasilicate (ks), $K_2O.SiO_2$, as well—an extremely rare occurrence. The minor inflexible molecules in the femic group are magnetite, chromite, hematite, ilmenite, titanite, perofskite, rutile, apatite, fluorite, calcite, and pyrite. Magnetite and hematite have been introduced in preceding analyses; chromite is made in Analysis S, perofskite in Analysis S, rutile is considered in the present analysis, calcite appears in Analysis O, and pyrite in Analysis K. In the salic group we have the minor inflexible molecules zircon, sodalite, and noselite. Zircon appears in Analysis M, and sodalite and noselite in Analysis O.

Following the order stated on p. 188, sec. 3, in the *Quantitative Classification of Igneous Rocks*, Cr_2O_3 not being present, we first allot FeO to TiO_2 for ilmenite (il), in the proportion 1:1. TiO_2 remaining over takes CaO and SiO_2 for titanite (tn), $CaO.TiO_2.SiO_2$, in the proportion 1:1:1. We are working with an analysis in which the amount of SiO_2 is sufficient to meet all claims upon it. If silica were not abundant TiO_2 remaining over after the allotment for ilmenite would take CaO for perofskite (pf), $CaO.TiO_2$, in the proportion 1:1. Such a case is given in Analysis S. Here if TiO_2 after the allotments for ilmenite and titanite still remained over, it would be considered as rutile (ru), TiO_2. In the next place P_2O_5 takes $3\frac{1}{3}$ times as many units of CaO as there are units of P_2O_5, and $\frac{1}{3}$ as much F or Cl, for apatite (ap), $3CaO.P_2O_5+\frac{CaCl_2}{3}$ or $3CaO.P_2O_5+\frac{CaF_2}{3}$ in the ratio $CaO:P_2O_5$ as $3\frac{1}{3}$:l, and F or Cl, to satisfy CaO, equal to $\frac{1}{3}P_2O_5$. In the next place fluorine (F=26), takes $\frac{1}{2}$ as much CaO for fluorite (ft), CaF_2. After these minor inflexible molecules have been adjusted K_2O is allotted for orthoclase with the

ANALYSIS H

VARINGOSE (PANTELLERITE). *Professional Paper 14*, p. 218, No. 4

Pantelleria

Percentage	SiO_2 70.30	Al_2O_3 6.32	Fe_2O_3 9.23	FeO 1.40	MgO 0.89	CaO 0.84	Na_2O 7.70	K_2O 2.50	H_2O 0.82	Sum 100.00				
Molecular Proportions	1.172	.062	.058	.019	.022	.015	.124	.026	Salic Minerals		Femic Minerals			
	156	26						26	or	14.5				
	216	36					36		ab	18.9				
	232		58				58				ac	26.8		
	30						30				ns	3.7		
	30			7	8	15					di	3.5	$CaO.SiO_2$	1.74
													$MgO.SiO_2$	.800
													$FeO.SiO_2$	.92
	26			12	14						hy	3.0	$MgO.SiO_2$	1.400
													$FeO.SiO_2$	1.58
	482								Q	28.9				
									Sal.	62.3	Fem.	37.0		
									Fem.	37.0				
									H_2O	.82				
									Sum	100.12				

ANALYSIS I

ORENDOSE (ORENDITE). *Professional Paper 44*, p. 312, No. 2
Leucite Hills, Wyom.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Ka_2O	K_2O	TiO_2	P_2O_5	Cl	F	H_2O	Sum				
Percentage	54.08	9.49	3.19	1.03	6.74	3.55	1.39	11.76	2.08	1.35	0.04	0.49	3.50	99.76				
Molecular Proportions	.901	.003	.020	.014	.169	.063	.022	.145	.026	.009	.001	.026	Salic Minerals		Femic Minerals			
				14					14						il	2.1		
	12					12			12						tn	2.4		
						30				9	1				ap	3.0		
						13						26			ft	1.0		
	558	93						93					or	51.7				
	32							32							ks	4.9		
	80		20				20								ac	9.2		
	2						2								ns	.2		
																	CaO.SiO_2	.93
	16			0	8	8									di	1.7	MgO.SiO_2	.800
																	FeO.SiO_2	.00
	161			0	161										hy	16.1	MgO.SiO_2	16.000
																	FeO.SiO_2	.00
	40												Q	2.4				
													Sal.	54.1	Fem.	40.6		
													Fem.	40.6				
													H_2O	3.50				
													Sum	98.20				

available Al_2O_3, 93, and SiO_2. The K_2O remaining over is allotted to potassium metasilicate (ks), $K_2O.SiO_2$, with SiO_2, in the ratio 1:1. After all the K_2O has been used Na_2O takes Fe_2O_3, as far as Fe_2O_3 is available (there being no Al_2O_3 left to unite with it), and SiO_2, for acmite. Na_2O still remaining over is sodium metasilicate. CaO remaining after the foregoing assignments takes MgO and FeO in the requisite amounts, and in the ratio in which they stand, 8:0, for diopside (di). MgO remaining, there being no FeO, is allotted to hypersthene, and the SiO_2 which has not been used is quartz.

All the analyses thus far presented, from A to I inclusive, have been those in which SiO_2 is abundant. The calculation of analyses in which SiO_2 is relatively low is usually more difficult. Orthoclase (or), $K_2O.Al_2O_3.6SiO_2$, requires more silica than leucite (lc), $K_2O.Al_2O_3.4SiO_2$, and leucite requires more silica than kaliophilite (kp), $K_2O.Al_2O_3.2SiO_2$. In the same way albite (ab), $Na_2O.Al_2O_3.6SiO_2$ requires more silica than nephelite (ne), $Na_2O.Al_2O_3.2SiO_2$. It should be noted that the ratio between K_2O and Al_2O_3 is always as 1:1 in orthoclase, leucite, and kaliophilite, and that the ratio between Na_2O and Al_2O_3 is always 1:1 in albite and nephelite. Hypersthene (hy), $(MgFe)O.SiO_2$ requires more silica than olivine (ol), $2(MgFe)O.SiO_2$, for the same amount of (MgFe)O. With low silica, therefore, a substitution is made of one or more minerals which require less silica than the minerals employed in the straightforward calculations thus far considered.

Where silica is low the simplest adjustment is that illustrated by Analysis J. Here the minor inflexible molecules, ilmenite (il), and apatite (ap), are first calculated. In this analysis apatite cannot get its quota of Cl or F, for these elements have not been determined. The molecular weight is however taken as 336, and the percentage weight of the mineral obtained by multiplying the amount of P_2O_5 by 336. The table on p. 258 for the percentage weights of apatite is based on a molecular weight of 336, F or Cl having been available. Al_2O_3 is present in sufficient amount to allow with silica for the formation of orthoclase (or), albite (ab), and anorthite (an). After the allotments for magnetite (mt), and diopside (di), there remain of MgO 67, and of FeO 20 units. The silica available at this point is 62. This is not enough to make hypersthene with the MgO and

FeO, for which 87 molecular proportion units of SiO_2 would be needed. If we should take the MgO and FeO with silica for olivine (ol), $2(MgFe)O.SiO_2$, in the proportion 2:1, then silica would be left over in amount equal to 18 units. The formulated method for calculating the norm does not admit of our making olivine at this point with (MgFe)O and silica, and then calling the remaining silica quartz. This accords with the fact that quartz and olivine are very rarely found together in igneous rocks. What we do is to divide the MgO, FeO, and available silica between hypersthene and olivine, making use of two simple algebraic equations.

Let x = the number of hypersthene molecules
and y = the number of olivine molecules;
then $x+y$ = the number of units of (MgFe)O
and $x+\frac{y}{2}$ = the number of units of SiO_2,
or $x+y=87$
and $x+\frac{y}{2}=62$
$\frac{y}{2}=25$
$y=50$ = molecules of olivine
and $x=37$ = molecules of hypersthene.

MgO and FeO are to be introduced in hypersthene and in olivine in the same ratio in which they were used in diopside. The ratio in this case is 20:67 or, nearly, $1:3\frac{1}{3}$.

It is to be noted in connection with the use of the tables that olivine is the sum of two parts, $2MgO.SiO_2$ and $2FeO.SiO_2$. We look up the first of these on p. 255, and use in looking it up one-half the amount of MgO units, i. e., $\frac{39}{2}$, not 39.; and in the same way we look up one-half the amount of FeO units, or $5\frac{1}{2}$, not 11, on p. 256, and add our findings together for olivine.

Analysis K illustrates the same points as J, but in it pyrite is introduced, FeS_2 having been present in the rock.

x = the number of hypersthene molecules
y = the number of olivine molecules
$x+y=139=(MgFe)O$
$x+\frac{y}{2}=88=SiO_2$
$\frac{y}{2}=51$, $y=102$, and $x=37$.

ANALYSIS J

ANDOSE (DIORITE). *Professional Paper 14*, p. 272, No. 11
Crazy Mountains, Mont.

Percentage	SiO_2 50.73	Al_2O_3 19.99	Fe_2O_3 3.20	FeO 4.66	MgO 3.48	CaO 8.55	Na_2O 4.03	K_2O 1.89	TiO_2 1.59	P_2O_5 0.81	H_2O .077	Sum 100.13			
Molecular Proportions	.846	.196	.020	.066	.087	.155	.065	.020	.020	.006	Salic Minerals		Femic Minerals		
				20					20				il	3.0	
						18				6			ap	2.0	.006 × 336
	120	20						20			or	11.1			
	390	65					65				ab	34.1			
	222	111				111					an	30.9			
			20	20									mt	4.6	
	52			6	20	26							di	5.8	$CaO.SiO_2$ 3.02; $MgO.SiO_2$ 2.000; $FeO.SiO_2$ .79
Remainder at this point → SiO_2 62, MgO 67, FeO 20	37			9	28								hy	4.0	$MgO.SiO_2$ 2.800; $FeO.SiO_2$ 1.19
	25			11	39								ol	3.9	
											Sal.	76.1	Fem.	23.3	
											Fem.	23.3			
											H_2O	.77			
											Sum	100.17			

NOTE.—With FeO, MnO .001 has been added in. BaO, .002 have been added to CaO.

ANALYSIS K

HESSOSE (AMPHIBOLE GABBRO). *Classification of Igneous Rocks*, p. 199

Big Trees Quadrangle, Cal.

Percentage	SiO_2 47.27	Al_2O_3 20.82	Fe_2O_3 1.85	FeO 4.26	MgO 6.44	CaO 13.02	Na_2O 2.75	K_2O 0.22	TiO_2 0.92	P_2O_5 0.74	FeS_2 0.20	H_2O 1.35	Sum 99.84				
Molecular Proportions	.788	.204	.011	.059	.161	.232	.044	.002	.011	.005		Salic Minerals		Femic Minerals			
						15				5				ap	1.6		
				11					11					il	1.7		
	12	2						2				or	1.1				
	246	44					44					ab	23.1				
	306	158				158						an	43.9				
			11	11										mt	2.6		
																$CaO.SiO_2$	6.84
	118			11	48	59								di	13.1	$MgO.SiO_2$	4.800
																$FeO.SiO_2$	1.45
	37			7	30									hy	3.9	$MgO.SiO_2$	3.000
																$FeO.SiO_2$	.92
	51			19	83									ol	7.7	$2MgO.SiO_2$	5.80
																$2FeO.SiO_2$	1.94
												Sal.	68.1	FeS_2	.2		
												Fem.	30.8				
												H_2O	1.35	Fem.	30.8		
												Sum	100.25				

It is to be noted that with quartz we will not have olivine in the norm and vice versa.

By making some hypersthene and some olivine, therefore, we can allow for a small shortage of SiO_2. If we attempt to calculate Analysis L in the same manner it is found that after making orthoclase (or), albite (ab), anorthite (an), magnetite (mt), diopside (di), and olivine (ol), 219 more units of silica have been called for than are available. The silica deficit is too great to be treated as in the preceding example.

ANALYSIS L. TENTATIVE

LAURDALOSE (SYENITE PEGMATITE). *Professional Paper 14*, p. 296, No. 14

Stoksund, Norway

Percentage	SiO_2 53.81	Al_2O_3 19.69	Fe_2O_3 .620	FeO .363	MgO .085	CaO .173	Na_2O 7.77	K_2O 4.58	H_2O 1.52	Sum 99.78	
Molecular Proportions	.897	.193	.039	.050	.021	.031	.125	.049	Salic Minerals		Femic Minerals
	294	49						49	or		
	750	125					125		ab		
	38	19				19			an		
			39	39							mt
	24			4	8	12					di
	10			7	13						ol

1,116 SiO_2 have been allotted at this point.
897 available SiO_2

219 SiO_2 deficit for this distribution

In the tentative distribution albite (ab) calls for 6×125, or 750, SiO_2. Nephelite would use up only 250, or 2×125, SiO_2. If we allot in the first place (holding out the soda, Na_2O, 125, and equal Al_2O_3, 125) the proper amounts of the various oxides for orthoclase (or), anorthite (an), magnetite (mt), diopside (di), and olivine (ol), we shall have 531 units of SiO_2 left, to go with the 125 Na_2O and 125 Al_2O_3. What we do then is to make a certain amount of albite and a certain amount of nephelite. It is to be remembered that in any allotment of Na_2O and Al_2O_3 to albite (ab), $Na_2O.Al_2O_3.6SiO_2$, and nephelite (ne), $Na_2O.Al_2O_3.2SiO_2$, the ratio of Na_2O to Al_2O_3 will be as 1:1. Being silica poor we made olivine (ol), with (MgFe)O and not hypersthene. The formulas for the distribution of Na_2O, Al_2O_3, and SiO_2 between albite and nephelite are as follows:

Let x = the number of albite molecules
Let y = the number of nephelite molecules
then $x+y=Na_2O=Al_2O_3$
and $6x+2y=SiO_2$
$x+y=125$
$6x+2y=531$
$2x+2y=250$
subtracting $4x=281$
$x=70$ molecules of albite
$y=55$ molecules of nephelite.

It is clear that with nephelite in the norm we shall not have quartz.

Analysis M proceeds on the same lines as L except that the minor inflexible molecule zircon (Z), is first introduced, taking $ZrO_2 = SiO_2$ in accordance with its formula $ZrO_2.SiO_2$.

In N we have a case with SiO_2 still lower than in M. If we attempt to calculate it in the same way as L and M we find that we have run over on SiO_2 by 21 units, holding out $Na_2O.Al_2O_3$, 45, for albite and nephelite, and making the allotments for apatite, orthoclase, anorthite, magnetite, diopside, and olivine. We have therefore no SiO_2 with which to make even nephelite with the 45 $Na_2O.Al_2O_3$ held out in the beginning.

There is not enough SiO_2 therefore to begin the calculation by making orthoclase. This case is analogous to the situation in L and M where Na_2O is distributed between albite and nephelite. We proceed by holding out all the K_2O and equal Al_2O_3 for a certain amount of orthoclase, and a certain amount of leucite ($K_2O.Al_2O_3.4SiO_2$), which calls for less SiO_2 than orthoclase does. These minerals will each use up K_2O and Al_2O_3 in the ratio 1:1. The Na_2O is allotted with Al_2O_3 and SiO_2 to nephelite. This is much lower in SiO_2 than albite is. Anorthite, magnetite, diopside, and olivine are then made. The SiO_2 remaining over is 369. This is given to the $K_2O.Al_2O_3$, previously set aside, for orthoclase and leucite, by means of the equations where

x = the number of molecules of orthoclase
and y = the number of molecules of leucite
$x+y=K_2O$
and $6x+4y=SiO_2$
Here $x+y=80$
$6x+4y=369$
$x=24$
and $y=56$.

ANALYSIS L

LAURDALOSE (SYENITE PEGMATITE). *Professional Paper 14*, p. 296, No. 14

Stoksund, Norway

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Sum	
Percentage	53.81	19.69	6.20	3.63	0.85	1.73	7.77	4.58	1.52	99.78	
Molecular Proportions	.897	.193	.039	.050	.021	.031	.125	.049	Salic Minerals		Femic Minerals
	294	49						49	or	27.2	
	420	125 { 70					125 { 70		ab	36.7	
	110	55					55		ne	15.6	
	38	19				19			an	5.3	
			39	39							mt 9.1
	24			4	8	12					di 2.7 { $CaO.SiO_2$ 1.39, $MgO.SiO_2$ .800, $FeO.SiO_2$ .53
	10			7	13						ol 1.6 { $2MgO.SiO_2$ .91, $2FeO.SiO_2$ .71
	896								Sal.	84.8	Fem. 13.4
									Fem.	13.4	
									H_2O	1.52	
									Sum	99.72	

ANALYSIS M

Lujavrose (Lujaurite). *Professional Paper 14*, p. 303, last section, No. 1
Kangerdluarsuk, Greenland

Percentage	SiO_2 51.62	Al_2O_3 15.63	Fe_2O_3 6.06	FeO 4.98	MgO Tr	CaO 3.45	Na_2O 10.09	K_2O 4.19	ZrO_2 2.14	H_2O 2.12	Sum 100.61				
Molecular Proportions	.860	.153	.038	.069		.062	.163	.045	.017	Salic	Minerals	Femic Minerals			
	17								17	z	3.1				
	270	45						45		or	25.0				
	90	108 { 15					108 { 15			ab	7.9				
	186	93					93			ne	26.4				
	152		38				38					ac	17.6		
	17						17					ns	2.1		
	124			62	0	62						di	15.4 {	$CaO.SiO_2$	7.19
														$MgO.SiO_2$	.000
														$FeO.SiO_2$	8.18
	4			7	0							ol	.7 {	$2MgO.SiO_2$	.00
														$2FeO.SiO_2$	.71
										Sal.	62.4	Fem.	35.8		
										Fem.	35.8				
										H_2O	2.12				
										Sum	100.32				

ANALYSIS N. TENTATIVE

VESUVOSE (LEUCITE BASANITE). *Professional Paper 14*, p. 306, No. 2

Lava of 1872, Mount Vesuvius

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O	Sum	
Percentage	47.65	19.28	2.63	6.48	4.19	9.01	2.78	7.47	0.50	0.24	100.23	
Molecular Proportions	.794	.189	.016	.090	.085	.161	.045	.080	.004	Salic Minerals		Femic Minerals
						12			4			ap
	480	80						80		or		
		45					45			ab ne		
	128	64				64				an		
			16	16								mt
	170			40	45	85						di
	37			34	40							ol
	815											
	794											
	21	SiO_2										

With leucite and nephelite there will be no quartz nor will there be hypersthene. With leucite in the norm there will be no albite.

ANALYSIS N

VESUVOSE (LEUCITE BASANITE). *Professional Paper 14*, p. 306, No. 2

Lava of 1872, Mount Vesuvius

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O	Sum	Femic Minerals	
Percentage	47.65	19.28	2.63	6.48	4.19	9.01	2.78	7.47	0.50	0.24	100.23		
Molecular Proportions	.794	.189	.016	.090	.085	.161	.045	.080	.004	Salic Minerals			
						12			4			ap	1.3
	144	80 { 24						80 { 24		or	13.3		
	224	56						56		lc	24.4		
	90	45					45			ne	12.8		
	128	64				64				an	17.8		
			16	16								mt	3.7
	170			40	45	85						di	19.6
	37			34	40							ol	6.3
										Sal.	68.3	Fem.	30.9
										Fem.	30.9		
										H_2O	.24		
										Sum	99.44		

Analysis O is like N, where K_2O goes partly to orthoclase and partly to leucite, but here we make the minor inflexible molecules

ANALYSIS O

JANEIROSE (PSEUDO-LEUCITE-SODALITE-TINGUAITE). *Classification of Igneous Rocks*, p. 203

Bearpaw Mountains, Mont.

Percentage	SiO_2 51.93	Al_2O_3 20.29	Fe_2O_3 3.59	FeO 1.20	MgO 0.22	CaO 1.65	Na_2O 8.49	K_2O 9.81	TiO_2 0.20	SO_3 0.67	CO_2 0.25	Cl 0.70	F 0.27	H_2O 1.09	Sum 100.31			
Molecular Proportions	.866	.200	.022	0.18	.066	.030 BaO .001 SrO .001 .032	.137	.104	.002	.009	.006	.020	.014	Salic Minerals		Femic Minerals		
Note				2					2							il	.3	
						7							14			ft	.6	
							10					20		so	9.7			
						6	9			9				no	6.3			
											6					cc	.6	
	390	104 { 65						104 { 65						or	36.1			
	156	39						39						lc	17.0			
	192	96					96							ne	13.6			
	88		22				22									ac	10.2	
						19												$CaO.SiO_2$ 1.97
	38			14	5											di	4.3	$MgO.SiO_2$ .500
																		$FeO.SiO_2$ 1.85
	2			2	1											ol	.3	$2MgO.SiO_2$ .07
																		$2FeO.SiO_2$ .20
														Sal.	82.7	Fem. 16.3		
														Fem.	16.3			
														H_2O	1.09			
														Sum	100.09			

Sodalite (so) equals .010×969, or 9.69
Noselite (no) equals .009×699, or 6.29

NOTE.—The allotments of SiO_2 and Al_2O_3 to the nephelite (Na_2O. Al_2O_3. $2Si_2O$) element in sodalite and noselite have been summed with nephelite 96 (Na_2O·Al_2O_3. $2SiO_2$).

ilmenite (il), fluorite (ft), sodalite (so), noselite (no), and calcite (cc), at the outset. (See note at end of paper.) The formula for sodalite is $3(Na_2O.Al_2O_3.2SiO_2).2NaCl$ and that for noselite is $2(Na_2O.Al_2O_3.2SiO_2)Na_2SO_4$. Sodalite is therefore like the nephelite molecule taken three times with 2NaCl added. Where Cl occurs in notable amount with P_2O_5 present it is first allotted to apatite (see Analysis I), and the remainder then takes half as many units of Na_2O for 2NaCl in sodalite. One-half the number of units of Cl is the key. By multiplying this number, .010, by 969 (the molecular weight of sodalite), the percentage weight of sodalite (so) is obtained. Where SO_3 is present it takes an equal amount of Na_2O for Na_2SO_4 in noselite (no). The number of units of SO_3 is the key. By multiplying this number, .009, by 699 (the molecular weight of noselite), we get the percentage weight of noselite. In this calculation the nephelite molecules in sodalite (15), and in noselite (9), have been lumped in with nephelite. CO_2 when present in a rock usually points to a weathered condition in the rock, the mineral then being present as an alteration product. Where CO_2 occurs in a rock and is not a product of alteration, calcite is an original mineral constituent. In Analysis O we allot to 6 units of CO_2 as many units of CaO for calcite (cc), $CaO.CO_2$, the ratio between CaO and CO_2 being 1:1.

In the foregoing examples of calculation a shortage of SiO_2 was met by distributing $Na_2O.Al_2O_3$ between albite and nephelite, after making orthoclase with $K_2O.Al_2O_3$; or the shortage was provided against, after making nephelite, by distributing $K_2O.Al_2O_3$ between orthoclase and leucite. With SiO_2 too low for either of these alternatives we may allot $K_2O.Al_2O_3$ to leucite and $Na_2O.Al_2O_3$ to nephelite, using up in this way a relatively small amount of SiO_2. This is the procedure in Analysis P, where we make leucite, nephelite, anorthite, magnetite, diopside, and olivine, only to find that we have run over by 74 units of SiO_2. In making diopside we used 302 SiO_2. If now we take CaO from diopside, turn the MgO and FeO thus set free into more olivine, and use the lime (with the requisite amount of SiO_2) in ackermanite (am), $4CaO.3SiO_2$, which by its formula uses up less SiO_2 for the same amount of CaO than diopside does, we can do away with the SiO_2 deficit. When the ratios of CaO:SiO_2 in diopside, 1:2 (or 4:8), and in ackermanite, 4:3, are considered, it

ANALYSIS P. TENTATIVE

ALBANOSE (LEUCITITE). *Professional Paper 14*, p. 350, sec. 4, No. 1
Alban Hills, Italy

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O	Sum		
Percentage	45.99	17.12	4.17	5.38	5.30	10.47	2.18	8.97	0.37	0.45	100.65		
Molecular Proportions	.767	.168	.026	.075	.133	.187 .002 BaO .189	.035	.095	.005	Salic Minerals			Femic Minerals
				5					5				il
	380	95						95		lc			
	70	35					35			ne			
	76	38				38				an			
			26	26									mt
	302			38	113	151							di
	13			6	20								ol
	841												
	767												
	74 Deficit in SiO_2												

at once appears that ackermanite (am), is the mineral lower in SiO_2 for the same amount of CaO. By taking 96 CaO from the diopside and using with it 72 SiO_2 we make 24 molecules of ackermanite, i. e., 24 ($4CaO.3SiO_2$). By recalculating for new diopside and putting in the 24 molecules of ackermanite (am) (calling for 72 SiO_2 with 96 CaO), we find that as the result there is no deficit of SiO_2. To ascertain just the right amount of ackermanite to be introduced we make use of the simple formula where

y = the deficit of SiO_2

$\frac{y}{3}$ = the number of ackermanite molecules to be made.

It appears on trial of all such cases that the deficiency in SiO_2 is exactly allowed for when the number of ackermanite molecules made with CaO taken from diopside equals one-third of the SiO_2 deficit, and in consequence we take lime away from diopside equal to four times the number of ackermanite molecules. Numerically it is found that for every unit of CaO taken from diopside and used in ackermanite we gain three-fourths of a unit in silica, though the process involves the making of new olivine which itself uses up silica. So then to make up a deficit of 74 SiO_2 we need to take 96 CaO from diopside, 96 CaO + 72 SiO_2 making 24 molecules of ackermanite.

In P, therefore, we first allot for ilmenite, leucite, nephelite, anorthite, and magnetite. Then, for ackermanite, 96 CaO units are taken from diopside previously made, and used with 72 SiO_2 for ackermanite in accordance with the formula $4CaO.3SiO_2$. In looking up the percentage weight of ackermanite (am), in the table on p. 256 the unit of calculation is 24, not 96; i. e., it is one-fourth the molecular proportion of CaO in the ackermanite. The 55 units of CaO left over from the original diopside assignment are allotted for new diopside, and the MgO and FeO thus set free go to olivine.

It should be noted that in this analysis after making diopside there is no excess of CaO to be set aside for the making of wollastonite (cf. Analysis F). In the following example (Q), 95 molecular-proportion units of CaO are left over after the making of diopside for wollastonite.

The calculation of Analysis Q differs from that of the preceding example, as was noted just above, in that CaO in the tentative allotment is found to cover the MgO and FeO for diopside and to remain over after this in amount equal to 95 units. These are given to wollastonite (wo), $CaO.SiO_2$. The silica deficit is 78. By turning 92 of the 95 CaO of the wollastonite into ackermanite (making in such a case 23 molecules of ackermanite calling for 92 CaO and 69 SiO_2), we can do away with a deficit of silica equal to 23. If then our silica deficit were not 78 as it is in this analysis but only 23 or less, enough CaO set aside for wollastonite could be converted into ackermanite in this manner to do away with the silica deficit. The formula used is, where y = the silica deficit, y = as well the number of ackermanite molecules to be made. This alternative is not open to us in this analysis but it is clear how such calculations are to be treated when they arise. In this case, with insufficient molecules of wollastonite to satisfy the deficit of SiO_2 by their conversion into ackermanite, the molecules of both diopside and wollastonite are to be recalculated to make new diopside, new olivine, and ackermanite by the following equations.

Let x = the molecules of new diopside
y = the molecules of ackermanite
z = the molecules of new olivine.

Then $2x+3y+\frac{z}{2}$ = the available SiO_2
$x+4y$ = the available CaO
$x+z$ = the available (MgFe)O.

ANALYSIS P

ALBANOSE (LEUCITITE). *Professional Paper 14*, p. 350, sec. 4, No. 1

Alban Hills, Italy

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O	Sum			
Percentage	45.99	17.12	4.17	5.38	5.30	10.47	2.18	8.97	0.37	0.45	100.65			
Molecular Proportions	.767	.168	.026	.075	.133	.187 BaO .002 / .189	.035	.095	.005	Salic Minerals		Femic Minerals		
				5					5			il	.8	
	380	95						95		lc	41.4			
	70	35					35			ne	9.9			
	76	38				38				an	10.6			
			26	26								mt	6.0	
	72					96						am	9.7	
	110			14	41	55						di	12.3	$CaO.SiO_2$ 6.38; $MgO.SiO_2$ 4.100; $FeO.SiO_2$ 1.85
	61			30	92							ol	9.5	$2MgO.SiO_2$ 6.44; $2FeO.SiO_2$ 3.06
										Sal.	61.9	Fem.	36.3	
										Fem.	36.3			
										H_2O	.45			
										Sum	98.65			

ANALYSIS Q

COVOSE (NEPHOLITE SYENITE). *Professional Paper 14*, p. 352, No. 2

Magnet Cove, Ark.

Percentage	SiO_2 38.93	Al_2O_3 15.41	Fe_2O_3 5.10	FeO 4.24	MgO 5.57	CaO 16.49	Na_2O 5.27	K_2O 1.78	TiO_2 1.62	P_2O_5 0.35	H_2O 5.02 / Sum 100.57		
Molecular Proportions	.649	.151	.032	.059	.139	.294	.085	.019	.020	.002	Salic Minerals	Femic Minerals	Tentative
						6				2		ap .7	
				20					20			il 3.0	
	76	19						19			lc 8.3		
	170	85					85				ne 24.1		
	94	47				47					an 13.1		
			32	32								mt 7.4	
Tentative →	(292)			(7)	(139)	(146)							di
Tentative	(95)					(95)							wo
Note													
	146			4	69	73						di 15.9 { $CaO.SiO_2$ 8.47, $MgO.SiO_2$ 6.900, $FeO.SiO_2$ .53 }	
	36			3	70							ol 5.2 { $2MgO.SiO_2$ 4.90, $2FeO.SiO_2$ .30 }	
	126												
	168					168						am 17.0	
											Sal. 45.5	Fem. 49.2	
											Fem. 49.2		
											H_2O 5.20		
											Sum 99.9		

NOTE.—A deficit of 78 SiO_2 results from this tentative assignment.

In this calculation the available SiO_2 is 309, the CaO 241, and the (MgFe)O, 146.

$$\text{Therefore (1) } 2x+3y+\frac{z}{2}=309$$

$$\text{(2) } x+4y \quad =241$$

$$\text{and (3) } x+z \quad =146.$$

From (2), multiplying by 2,

$$2x+8y=482;$$

$$\text{(1) } 2x+3y+\frac{z}{2}=309;$$

$$\text{subtracting } 5y-\frac{z}{2}=173$$

$$\text{or } 10y-z=346.$$

$$\text{Again (2) } x+4y=241$$

$$\text{(3) } x+z=146;$$

$$\text{subtracting } 4y-z=95$$

$$10y-z=346$$

$$4y-z=95$$

$$y=42, \text{ ackermanite}$$

$$x=73, \text{ new diopside}$$

$$z=73, \text{ new olivine.}$$

With silica still lower than in Analysis Q we make such a calculation as is given in Analysis R. Here, after the assignment for ilmenite the K_2O, 79 units, is held out with equal $Al_2O_3.Na_2O$, takes Al_2O_3 as far as it is available (17), and SiO_2 for nephelite. Extra Na_2O, 9, takes Fe_2O_3 and SiO_2 for acmite. Fe_2O_3 remaining takes equal FeO for magnetite. All the CaO, 296 units, is calculated as ackermanite, and MgO and FeO remaining over take SiO_2 for olivine. Silica is left equal to 204 units. This is distributed with the 79 $K_2O.Al_2O_3$ held out (ante), between leucite and kaliophilite (kp), $K_2O.Al_2O_3.2SiO_2$. The equations are

$$x+y=K_2O$$

$$4x+2y=SiO_2$$

where x = the number of molecules of leucite
and y = the number of molecules of kaliophilite.

$$\text{(1) } x+y=79, \ K_2O$$

$$\text{(2) } 4x+2y=204, \ SiO_2.$$

$$\text{From (1) } 2x+2y=158$$

$$2x=46$$

$$x=23, \text{ leucite molecules}$$

$$y=56, \text{ kaliophilite molecules.}$$

Kaliophilite takes only half as much silica to go with a like amount of $K_2O.Al_2O_3$ as leucite would take, and only a third as much as orthoclase.

ANALYSIS R

VENANZOSE (EUKTOLITE). *Professional Paper 14*, p. 357, last analysis
San Venanzo, Umbria, Italy

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	H_2O	Sum	
Percentage	41.43	9.80	3.28	5.15	13.40	16.62	1.64	7.40	0.29	1.11	100.12	
Molecular Proportions	.691	.096	.021	.072	.335	.296	.026	.079	.004	Salic Minerals		Femic Minerals
				4					4			il .6
	92	79 { 23						79 { 23		lc	10.0	
	112	56						56		kp	17.7	
	34	17					17			ne	4.8	
	36		9				9					ac 4.2
			12	12								mt 2.8
	222					296						am 29.1
	195			56	335							ol 29.2
										Sal.	32.5	Fem. 65.9
										Fem.	65.9	
										H_2O	1.11	
										Sum	99.51	

It will be noted that the series of analyses from J to R inclusive illustrates a series of alternative methods for dealing with low SiO_2. A slight deficit may be adjusted between hypersthene and olivine. By this device we can do away with a silica deficit equal to one-half (MgFe)O. A larger deficit may be provided against by making albite with nephelite after having made orthoclase, under the conditions given above. This saving of silica amounts to a little less than four times the Na_2O. A still larger deficiency in SiO_2 may be provided for by allotting for orthoclase and leucite after making nephelite. Our making nephelite first in this case saves us an amount of SiO_2 equal to four times the units of Na_2O, and the subsequent distribution saves a little less than two times the amount of K_2O. With silica still lower it is necessary after making leucite and nephelite, thus saving two times the units of K_2O plus four times the Na_2O, to bring in ackermanite, a device which then saves three fourths of a unit of SiO_2 for every unit of CaO taken from diopside for ackermanite, or one silica on every four converted from wollastonite

ANALYSIS S

SVERIGARE (MELILITE BASALT). *Professional Paper 14*, p. 364, sec. 4, No. 1
Hohenstoffeln, Hegan, Baden

Percentage	SiO_2 35.56	Al_2O_3 11.25	Fe_2O_3 6.62	FeO 6.67	MgO 14.68	CaO 8.99	Na_2O 3.86	K_2O 1.75	TiO_2 8.03	Cr_2O_3 2.66	H_2O n.d.	Sum 100.07		
Molecular Proportions	.593	.110	.041	.093	.367	.177	.062	.019	.100	.018	Salic Minerals		Femic Minerals	Tentative
				18						18			cm 4.0 .018×224	
				75					75				il 11.4	
						25			25				pf 3.4	
			41										hm 6.6	
	76	19						19			lc	8.3		
	124	62					62				ne	17.6		
	58	29				29					an	8.1		
Tentative	(246)			(0)	(123)	(123)								di
Tentative	(122)			(0)	(244)									ol
SiO_2 deficit equals 33	158			0	79	79							di 17.1 { $CaO.SiO_2$ 9.16, $MgO.SiO_2$ 7.900, $FeO.SiO_2$ .00 }	
	144			0	288								ol 20.2 { $2MgO.SiO_2$ 20.16, $2FeO.SiO_2$ .00 }	
	33					44							am 4.4	
											Sal.	34.0	Fem. 67.1	
											Fem.	67.1		
											H_2O			
											Sum	101.1		

into ackermanite. With silica lower still it is necessary to expend as little of it as possible, making nephelite and ackermanite and distributing the silica then remaining between leucite and kaliophilite.

In Analysis S which is calculated like Analysis P, the first of the minor inflexible molecules to be made is chromite (cm), $FeO.Cr_2O_3$, the ratio between FeO and Cr_2O_3 being as 1:1. After ilmenite, which follows, we make perofskite (pf), $CaO.TiO_2$, with $CaO:TiO_2$ as 1:1. If silica has been present in abundance we should have made titanite instead of perofskite. (Cf. Analysis I.)

With the lowest-known ranges of SiO_2, in rocks in which aluminous spinel may form, Al_2O_3 and (MgFe)O being in excess, Al_2O_3 left over after making the feldspars, nephelite, or leucite, is corundum. MgO and FeO uncombined after their allotment to such minerals as magnetite and ilmenite may have to be entered with the femic minerals simply as MgO and FeO. Their percentage weights are determined by multiplying them by the molecular weights of MgO and FeO. Such a case is illustrated in Analysis T.

ANALYSIS T

(MAGNETITE SPINELLITE). *Professional Paper 14*, p. 368, last analysis

Routivaara, Finland

Percentage	SiO_2 4.08	Al_2O_3 6.40	Fe_2O_3 33.43	FeO 34.58	MgO 3.89	CaO 0.65	Na_2O 0.29	K_2O 0.15	TiO_2 14.25	Cr_2O_3 0.20	H_2O 1.32	Sum 99.71	
Molecular Proportions	.068	.063	.210 note	.480	.097	.011	.005	.002	.176	.001	Salic Minerals		Femic Minerals
				176					176				il 26.8
	12	2						2			or	1.1	
	30	5					5				ab	2.6	
	22	11				11					an	3.1	
		45									C	4.6	
			210	210									mt 48.7
					97								MgO 3.9
				94									FeO 6.9
											Sal.	11.4	Fem. 86.3
											Fem.	86.3	
											H_2O	1.32	
												99.02	

NOTE.—Cr_2O_3, .001, has been added to Fe_2O_3.

The student in calculating the analyses given in *Professional Paper 14* should not expect to agree exactly in all cases with the

calculated norms. Where additions as those of small amounts of BaO and SrO to CaO have not been made, slight discrepancies may result all along the line. Numerically the allotment to such minerals as diopside, hypersthene, and olivine may vary by a single unit one way or the other in MgO and FeO. The application of the methods of calculation given in the *Quantitative Classification of Igneous Rocks* should however be precise, the end in view being the correct placing of a given rock where it belongs in the scheme of classification. The method of calculating the norm is necessarily arbitrary in order that concordant results may be obtained by all who make use of it. It should be borne in mind, however, that it agrees with the great body of our observations on the occurrence of minerals in the igneous rocks. The work of calculation has therefore a peculiar value for the student, aside from his needs in classifying rocks, for it directs his thought toward the relations obtaining among the phenomena in cooling rock magmas. It brings home to him why it is that we do not have such an occurrence as that of quartz and nephelite together. It points out to him, for instance, the significance of the presence in a rock of such minerals as corundum, acmite, or perofskite rather than titanite, and it does much to make clear to his mind the significance of each of the mineral molecules occurring in the igneous rocks.

NOTE.—In "The Roman Comagmatic Region," *Publication 57 of the Carnegie Institution of Washington*, Dr. H. S. Washington has stated on p. 15 a modification of the method of calculation proposed by the authors of the quantitative system. This has to do with the normative minerals, sodalite and noselite. These mineral molecules are split up, and in their stead a statement is made in the norm of the amounts of halite (Hl), NaCl, and thenardite (Th), Na_2SO_4. SO_3 takes an equivalent number of molecular units of Na_2O to form thenardite, and Cl takes one-half its number of molecular units of Na_2O to form halite. "The soda which was previously combined with the sodium chloride and sulphate remains with the rest in calculating the norm, and, if necessary, is distributed between albite and nephelite in the usual way. An advantage of this method of procedure is that it minimizes the influence of the small amounts of Cl and SO_3 usually found, which is very great if they bind up in the norm a much greater amount of soda and silica."

THE OCCURRENCE OF A SAUROPOD DINOSAUR IN THE TRINITY CRETACEOUS OF OKLAHOMA

PIERCE LARKIN
Oklahoma Geological Survey

WITH AN INTRODUCTORY NOTE BY S. W. WILLISTON

Recently, during a visit to Norman, Oklahoma, Professor Gould, director of the State Geological Survey, called my attention to a large fossil bone which had lately been discovered in the Trinity Cretaceous of that state by Mr. Pierce Larkin of the survey. This specimen, clearly a morosaurian coracoid, furnishes the first indisputable evidence of the occurrence of the sauropod dinosaurs in the Cretaceous of western America. At my suggestion Mr. Larkin has prepared the following brief description of the Trinity deposits of Oklahoma, giving the precise horizon of the fossil. The precise taxonomic location of the specimen is not possible, since generic characters are not well displayed in the coracoids of the dinosaurs, and because of the partial mutilation of the specimen as it occurred in its matrix. Excellent figures of the specimen, furnished by Professor Gould, will render unnecessary a detailed description of the bone. The occurrence of the Sauropoda in the Lower Cretaceous is of course to be expected, since the recent discovery of similar remains in the Upper Cretaceous of Africa. I have long believed that the Morrison beds of the west are, in part at least, equivalent in age to the Comanche Cretaceous of the interior.—S. W. Williston.

The Trinity division of the Cretaceous of Texas contains three distinct formations, the Travis Peak, the Glen Rose, and the Paluxy. The Travis Peak and Paluxy are sand members, while the Glen Rose is calcareous. Toward the north this formation loses its distinctive characteristics and merges gradually into the sandy members above and below until one part of the Trinity cannot be distinguished from another. Throughout northern Texas and Oklahoma there is practically no change which could be made use of in separating

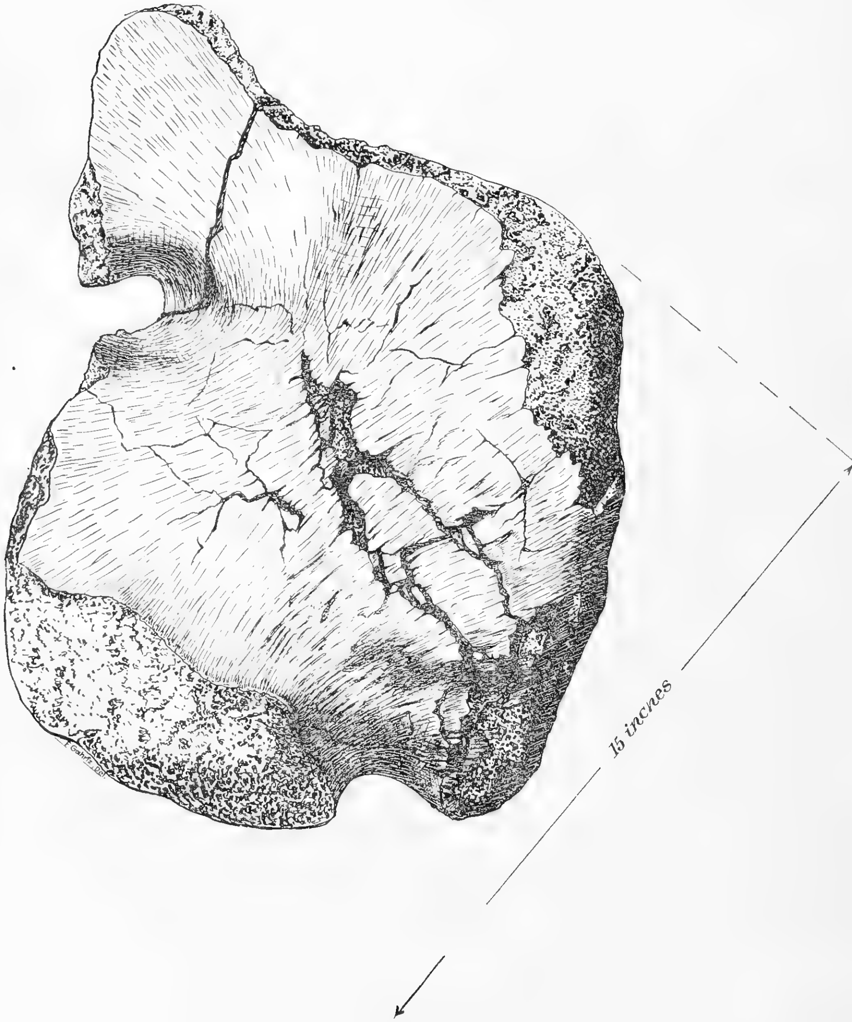


FIG. 1.—Right coracoid of sauropod, external side; one-fourth natural size.

the division into formations. There are no features which are continuous over large areas.

The Trinity enters Oklahoma from Texas near the western

FIG. 2.—Right coracoid of sauropod, upper border; one-fourth natural size.

line of Love County and leaves the state near the center of the McCurtain County line; and is mappable for a considerable distance in Arkansas. In Oklahoma it forms a broad sandy belt of country parallel to the axis of the Ouchita uplift. The average width of the outcrop is about 12 miles, and its length about 200 miles. The

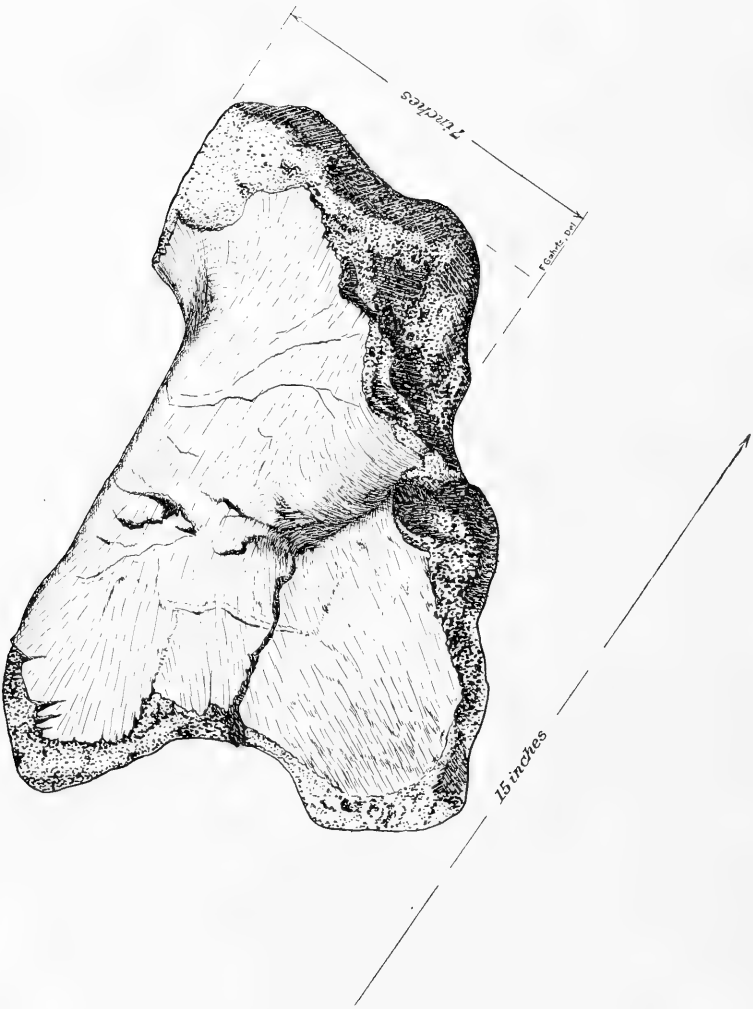


FIG. 3.—Right coracoid of sauropod, lower border; one-fourth natural size.

formation dips under other Cretaceous formations to the south and along Red River forms the reservoir of numerous artesian wells.

The thickness of the Trinity in Oklahoma varies from 200 to 800 feet.

The formation rests unconformably upon granites and Paleozoic rocks. It consists of conglomerates, unindurated or friable sandstones and clays mixed with varying quantities of sand. Most of this material bears evidence of being derived from adjoining rocks which formed the shore of the Cretaceous Sea. The conglomerates especially bear this characteristic. They always occur near the base of the formation and are formed of waterworn bowlders and pebbles of the rocks

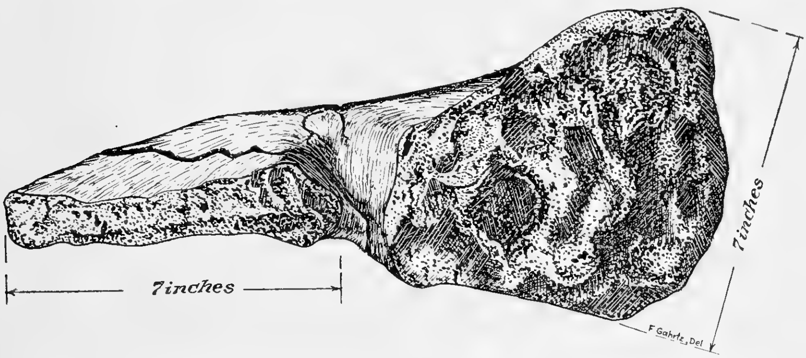


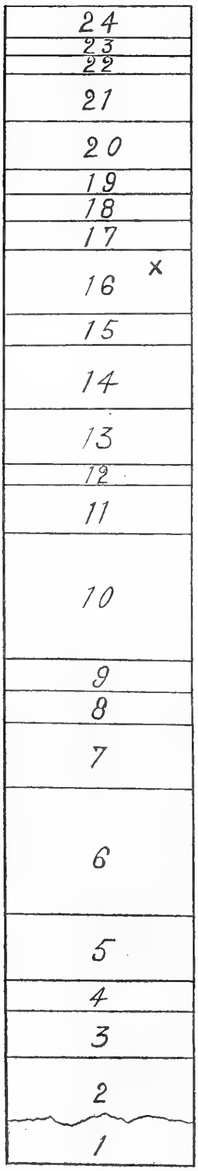
FIG. 4.—Right coracoid of sauropod, posterior border; one-fourth natural size.

upon which they rest, or of a formation near at hand. The sands and clays are not continuous over large areas but consist for the most part of lentils which are cross-bedded and irregularly thrown together. Everything points toward deposition in shallow turbulent water.

A following section across the Trinity along the line of the Missouri, Kansas and Texas Railroad from near Caddo, Oklahoma, to near Atoka, will give the reader some idea of the character of the Trinity at this place, and of the stratigraphic relations of the formations in which the bone was found.

The writer found the fossil dinosaur bone herewith figured in August, 1908, while making an examination of that region under the direction of the Oklahoma Geological Survey.

Section along the M. K. & T. Railroad, Caddo to Atoka, Okla.



		FEET
24	Goodland limestone white and massive . .	20
23	Gray marl	10
22	Yellow cross-bedded sand	12
21	White sand marly in places	30
20	Sand in matrix of yellow clay	30
19	Red and yellow sand with waterworn fragments of gypsum and Ostreae	12
18	Yellow and red arenaceous clay containing clay ironstone concretions	15
17	Yellow clay locally containing lentils of white sand	12
16	White and yellow sand much cross-bedded and containing lentils of yellow sandy clay. It is one of these lentils from which the bone came .	40
15	Yellow packsand with lenses of blue arenaceous clay and white sand	20
14	Gray sand in matrix of clay with lentils of brown and red sand. Concretions near the base	40
13	Green gray colored clays containing much sand	34
12	Red sand cross-bedded	12
11	Blue and yellow clay with lentils of yellow and white sand	30
10	The character of these formations could not be determined owing to river deposits . . .	80
9	Gray sandy clay	20
8	Yellow sandy clay	20
7	Yellow clay streaked with red and containing lentils of indurated sandstone	40
6	Valley of South Boggy Creek. The formations covered with alluvium	80
5	Gray sandy clay	40
4	Yellow arenaceous clay with lentils of brown packsand	20
3	Lentils of sand and gravel in beds of gray sandy clay	30
2	Grayish yellow clay with bowlders and lentils of conglomerate	40
1	Atoka formation, Carboniferous shale with lentils of sandstone	00

Reviews

Handbook for Field Geologists. By C. W. HAYES, PH.D., Chief Geologist U. S. Geological Survey. Pp. 159; 18 figures. New York: John Wiley & Sons, 1909.

This handbook of field methods will be found an important addition to the equipment of the working geologist. The basis of the present book was laid in an earlier volume on geologic field methods issued modestly in a limited edition in 1908 merely for distribution among members of the U. S. Geological Survey, but the frequency with which requests were made for it from members of the state surveys, teachers, mining geologists, and others indicated that a much wider need for such a book was felt, and it was in response to this demand that the present volume has been prepared.

The subject is treated under two main heads—Part I, general instructions, and Part II, instructions for special investigations. Part I covers the more common matters and the more specific instructions to members of the U. S. Geological Survey. Among these are included the field outfit, the more general lines of field observations, and measurements of structural features. These are accompanied by tables and formulas, and by the many graphic and trigonometric aids in solving problems connected with folds, faults, thickness of beds, etc. Upon these subjects much information is given in a condensed form. The taking of notes receives special attention; the purposes and the technique not only of written notes, but of graphic, photographic, traverse, plane table and profile notes, are carefully treated in detail and much attention is devoted to the methods of collecting material for further study and for museum exhibition. The various methods of surveying are also given an important place. The chief emphasis in this part is placed upon the necessity of using sound, accurate, and systematic methods in field work. It is an excellent exposition of the mechanical devices which have been long tried and found serviceable by the Federal Survey and, while doubtless not the last word, may be accepted as the teachings of mature experience.

Part II serves as a guidebook to the significant features to be observed in various special branches of field investigation and in its nature could not be equally complete. Pointers are given for the description and interpretation of land forms, for observations in petrologic and structural geology, for the study of glacial formations, and for the investigation of metalliferous

deposits. These discussions are followed by formal schedules or synopses upon fourteen special topics, such as, e.g., No. 4, Glaciers and glacial deposits; No. 14, Oil and gas. In these the salient features to be noted in the field are arranged in tabular form so as to be suggestive and directive to geologists, especially when working in lines outside their own special fields.

The book closes with an appendix giving a list of the official surveys of the United States, Canada, and Mexico, and the 33 states which conduct such surveys, together with the names of their directors in 1909 and an indication of the extent of their publications.

The booklet, strongly bound in flexible leather, is given a size convenient for use in the field and will be a welcome companion of many a working geologist.

R. T. C.

Geologie der Steinkohlenlager. VON DANNENBERG. Erster Teil, pp. 197, with 25 figures. Berlin: Gebrüder Borntraeger, 1909.

This work is a critical treatise upon the coal-bearing formations of Central Europe in which much attention is given to questions pertaining to the mode of origin of the coal and to the relation between the tectonics of the regions and the character of the coal. The stages in the development of the coals from the original vegetal matter through bacterial action, deformative movements of the strata, and igneous intrusions are carefully treated. Under the head of climatic and atmospheric conditions of the Carboniferous, the author discusses the older hypotheses of a heavy atmosphere, rich in carbon dioxide, and the newer view of an atmosphere with a limited fluctuating carbon dioxide content depending upon many factors. A close relation between extensive coal deposits and periods of unusual vulcanism which might be supposed to furnish the necessary carbon dioxide for the plant growth is sought, but no very apparent relation between the two is found. The Carboniferous was not preceded by any very unusual volcanic activity. To supply the carbon for the Coal Measures one would have to look back to the Devonian igneous activity. But in this discussion the author apparently fails to make use of the fact which he recognizes, namely, that much more carbon dioxide enters into the formation of limestone than is stored away in coal deposits. When it is considered that the atmosphere has been steadily contributing carbon dioxide to extensive limestone development throughout most of the sedimentary geologic history, the storage of carbon in coal beds at certain horizons in the Carboniferous, Cretaceous, Tertiary, etc., becomes less exceptional in its

tax upon the atmosphere and its accessions of gas from vulcanism than it might otherwise seem. The intimate association of glacial deposits with the Permo-Carboniferous coal beds in the comparatively low latitudes of India, South Africa, and Australia furthermore raise the suspicion that some of this vegetal accumulation at least may have taken place at a time when there was only a limited heat-absorbing and heat-retaining blanket of carbon dioxide about the earth.

In the special part is a discussion of the coals of the Carboniferous. This is followed by an excellent description of the salient features of the geology of the various coal districts in Europe in which are included something of the stratigraphy of the beds adjacent to the coal, the tectonics of each region, and the character of the coal developed under these conditions. The details of the geology of these special districts can of course be appreciated better by the European geologist than by those on this side of the Atlantic. They constitute the bulk of the book and appear to have been treated with much care and discrimination. The work is a valuable contribution to the literature of the coal formations.

R. T. C.

A Geologic Reconnaissance of the Island of Mindanao and the Sulu Archipelago. I. Narrative of the Expedition. By WARREN D. SMITH, Chief of Division of Mines. Philippine Jour. of Science, Dec., 1908, pp. 473–99, with 23 plates and 4 figures in the text.

Another instalment of the pioneer field work being done in the Philippine Islands by this active young geologist has come to hand. Up to this time very little has been known of the large southern island of Mindanao, partly because work in other important fields was more urgent and partly because of the hostility of the Moros. This paper gives a brief synopsis of the previous work of a geographic or geologic nature, a general geographic description, notes on the people and climate, and the itinerary and narrative of the expedition. The geologic observations appear with the text of the narrative. An excursion was made to the summit of Mount Apo, which, so far as known, is the highest peak in the Philippine archipelago. Two boiling-point determinations gave it an altitude of 2,956 and 2,902 meters, respectively.

In work of this sort many difficulties were naturally encountered and a military escort was required as a protection against the natives. Upon the basis of this reconnaissance the future detailed studies of this portion of the Philippine archipelago will be planned.

R. T. C.

Geology of the City of New York. By L. P. GRATACAP, A.M. 3d ed., Pp. 232, with 65 figures and 4 maps. New York: Henry Holt & Co., 1909.

The third edition of this work is much enlarged compared with the second, partly through additions of further geological studies of Manhattan Island by various investigators and also by an extension of the geology of Brooklyn and Long Island. It is perhaps because of the fact that this is a revision of an older volume that many antiquated views remain in the text. As an instance, one is struck in reading the introduction by the classification of the Quaternary (p. 8), where it is stated that "the Ice Age has been divided by some geologists (Chamberlin, Salisbury, Leverett) into two epochs—an early and later Ice Age—between which a reforestration of areas made bare and desolate by the ice took place." Such views were indeed held by these geologists twenty years ago, but they long ago recognized their inadequacy and the more complex nature of the Glacial series was described by Chamberlin in the résumé of American Glacial history which appeared in James Geikie's *Ice Age*, in 1895 and has been commonly given in more recent works.

The book describes the rocks of Manhattan Island, such as the gneiss proper, granite, mica schist, hornblende rocks, and limestones, gives their local occurrence and discusses certain problems connected with their origin, metamorphism, etc. There is a list and description of the minerals of Manhattan Island. These are followed by chapters on the Boroughs of Brooklyn, Bronx, and Richmond (Staten Island). The book closes with a chapter on "Evidences of Glaciation in and about Greater New York. The language of the opening pages of this chapter has been taken, as the author remarks in a footnote, from a former paper by himself which appeared in the *Popular Science Monthly* in 1878, and might well have been replaced by fresher matter. The book contains much of local historical and geographical interest. R. T. C.

Bulletin of the Scientific Laboratories of Denison University, Vol. XIV, Articles 6–10, pp. 61–188. Granville, O., April, 1909.

This University Bulletin contains the following articles of geologic interest:

6. Fossils from the Silurian Formations of Tennessee, Indiana, and Kentucky, by Aug. F. Foerste.

8. A Stratigraphic Study of Mary Ann Township, Licking County, Ohio, by Frank Carney.

9. Significance of the Drainage Changes near Granville, Ohio, by Earl R. Scheffel.

10. Age of the Licking Narrows, by K. F. Mather. R. T. C.

College Geology. By THOMAS C. CHAMBERLIN AND ROLLIN D. SALISBURY. Pp. 978, with 21 plates and 608 text figures. New York: Henry Holt and Co., 1909.

This book is essentially an abbreviation of the author's three-volume *Geology*, which appeared in 1904–6, with some changes of matter and mode of treatment and with many new illustrations. R. T. C.

Experimentaluntersuchungen über die auscheidungsfolge von silikaten bei zwei und drei componenten. By R. FREIS. Neues Jahrbuch für Mineralogie. Beilage, Band XXIII, 1907. 47 pp., 13 figs., 3 pls.

Freis gives the results of his studies on the freezing and melting curves, differentiation phenomena, and the sequence of crystallization of the following components:

I. Diopside and anorthite.
II. Diopside and olivine.
III. Diopside and nepheline.
IV. Diopside, anorthite, and magnetite.
V. Diopside, olivine, and magnetite.
VI. Diopside, olivine, and anorthite.
VII. Diopside, olivine, and nepheline.
VIII. Diopside, olivine, and orthoclase.

Various proportions of the chemically pure mineral constituents were melted, and cooled to glass. These glasses were heated in the electric furnace and the following temperatures noted:

T_1. The mass softens and takes slight impressions.
T_2. The mass has become entirely liquid.
T_3. Initial freezing point.
T_4. Freezing completed.

The freezing and melting curves descend to a minimum, lying between the two extremes of composition in the two component systems, indicating the presence of eutectics. Eutectics were also observed in nearly all the three component systems. Undercooling was a marked characteristic of all the freezing curves.

The sequence of crystallization was uniform for all systems, and was independent of the mineral proportions, and eutectics. Eutectic texture was absent. The following was the observed order for all proportions in the respective systems:

I. Diopside, anorthite, diopside.
II. Diopside, olivine.
III. Diopside, nepheline.
IV. Magnetite, diopside, augite, and anorthite.
V. Magnetite, olivine, and augite.
VI. Olivine, diopside, anorthite, and diopside.
VII. Olivine, diopside, and nepheline.
VIII. Olivine, diopside, and orthoclase.

Freis believes that the crystallization sequence followed Rosenbusch's law of increasing acidity of the magma, influenced by undercooling, the force of crystallization, and the solubility law of Nernst.

Differentiation phenomena consisting of local, ill-defined crystal aggregations or schlieren; sharply defined segregations of certain mineral aggregates; local variations in grain; and segregation in the inverse order of specific gravity were observed. Magnetite seemed to be segregated near the top of the melt. Forsterite or iron-free olivine, formed at the bottom, while iron-bearing diopside occupied an intermediate zone.

The order of crystallization and the differentiation phenomena observed by Freis therefore differ in many ways from certain generally accepted theoretical views on magmas.

E. S.

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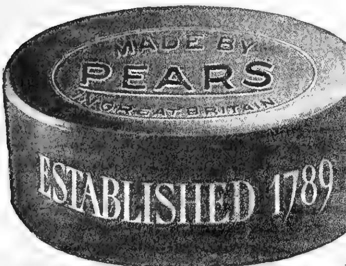

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JOURNAL OF GEOLOGY

FEBRUARY–MARCH, 1910

SUCCESSION AND RANGE OF MESOZOIC AND TERTIARY FLORAS[1]

F. H. KNOWLTON

X

It is of course a truism to say that the transition from the Paleozoic to the Mesozoic is not, as was once supposed, an abrupt or catastrophic change, but was brought about so gradually that in many parts of the world it is often difficult, if not indeed impossible, to draw any sharp lines. Not only are the rocks lithologically similar, but a certain percentage of life-forms persisted from the one to the other, yet when each system is considered in its entirety there are apparent abundant lithologic and strongly marked biologic differences. It is my purpose to speak briefly of the floras, first of the Mesozoic and later of the Tertiary.

Triassic.—Rocks of Triassic age are known in many parts of the world and indicate two types of deposition, a fresh-water, marsh, or lagoon phase, and a marine phase. The former is only, or largely, that which has afforded a flora. The known plants of the Trias are relatively few in number. In North America we have less than 150 species, and the entire Triassic flora probably does not exceed 300 or 400 forms. Owing to considerations, physical and otherwise, concerning which there is not complete agreement, the lower portions

[1] This article, which should have appeared as No. X in the series of correlation papers published last year, did not reach the *Journal* in time to be published in its proper place, in No. 6, 1909.

of the Trias afford but scanty remains, and it is not until we come to the upper portion, or Rhaetic, that it can really be dignified as a flora. Our North American Triassic flora is believed to belong largely to this portion. Triassic plants have been doubtfully reported from Prince Edward Island, but they are so obviously of Permian types that they may be disregarded. The principal areas are in North Carolina, Virginia, and Pennsylvania, with relatively few in Maryland, New Jersey, Connecticut, and Massachusetts. In the west we have a doubtful plant or two from Wyoming, a considerable number from northern New Mexico, the extensive fossil forests of Arizona, and a very few species from Plumas County, California. Going southward we have small collections from Sonora, from about the City of Mexico, in Honduras, Chile, and western Argentina. In other parts of the world Triassic floras have been found in England, east coast of Greenland, Spitzbergen, North Germany, southern Sweden, Italy, southwestern Spain, Persia, India, China, Tonkin, Japan, New South Wales, New Zealand, and South Africa.

What, now, are the characters of the Triassic flora? The dominant types of the Paleozoic have largely disappeared. The Lepidodendrae, Sigillariae, Calamites, Cordaites, Sphenophyllae, and Cycadofilices, so far as ascertained, have all gone, as well as a number of important genera of ferns—*Cheilanthites*, *Mariopteris*, *Megalopteris*, etc. The most notable survival from the Paleozoic is the so-called *Glossopteris* flora, which has been found with a few associated forms in Rhaetic rocks at Tonkin, the Stormberg series of South Africa, New South Wales, etc.

The Triassic flora consists essentially of equisetums, ferns, cycads, and conifers of many genera. A few forms such as *Ginkgo*, *Cladophlebis*, *Thinnfeldia*, etc., had a small beginning in the Paleozoic and expanded in the Mesozoic into large groups. But most of the flora is of distinctly Mesozoic and northern origin.

It has often been said that the plants of the Triassic are depauperate and pinched in aspect, indicating unfavorable climatic conditions. The paleobotanical facts do not altogether bear this out. In North Carolina, Virginia, and Arizona, there are trunks of trees preserved, some of which are 8 feet in diameter and at least 120 feet long, while hundreds are from 2 to 4 feet in diameter. Many of the

ferns are of large size, indicating luxuriant growth, while Equisetum stems 4 to 5 inches in diameter are only approached by a single living South American species. The cycads are not more depauperate than those of subsequent horizons, nor do they compare unfavorably with the living representatives.

The complete, or nearly complete absence of rings in the tree trunks indicate that there were no, or but slight, seasonal changes due to alternations of hot and cold, or wet and dry periods. The accumulations of coal—in the Virginia area aggregating 30 to 40 feet in thickness—indicate long-continued swamp or marsh conditions, while the presence of ferns, some of them tree-ferns, indicate on the whole a moist, warm, probably at least sub-tropical climate.

Jurassic.—Coming, now, to the Jurassic, we find in the lower portion indications of a continuation of conditions which obtained in the upper portions of the Trias. The distinctive Paleozoic elements had finally disappeared, and the Mesozoic life-forms were in full swing, expanding in the middle and upper parts of the period into the abundant and widespread flora as we know it. In fact the relative uniformity and wide extension of the Middle and Upper Jurassic flora is one of the most interesting and impressive exhibits that we have. (See map showing approximate distribution of Triassic and Jurassic flora.)

There is no paleobotanical evidence indicating the presence of the Jurassic in Eastern North America. In the western interior Jurassic plant-bearing beds occur in the Black Hills, South Dakota, and the Freezeout Hills, Carbon County, Wyoming. We then pass to the Pacific coast, where we have a fine flora near Oroville, California; also northward in Trinity and Tehama counties, California, and Douglas and Curry counties, Oregon.

The following is an outline of the world distribution of the flora:

Alaska	Copper River District
	Cook Inlet
	Herendeen Bay
	Cape Lisburne
England	Yorkshire
France	Mamers—northwestern portion
Germany	Franco-Swabian area
	Northwestern area

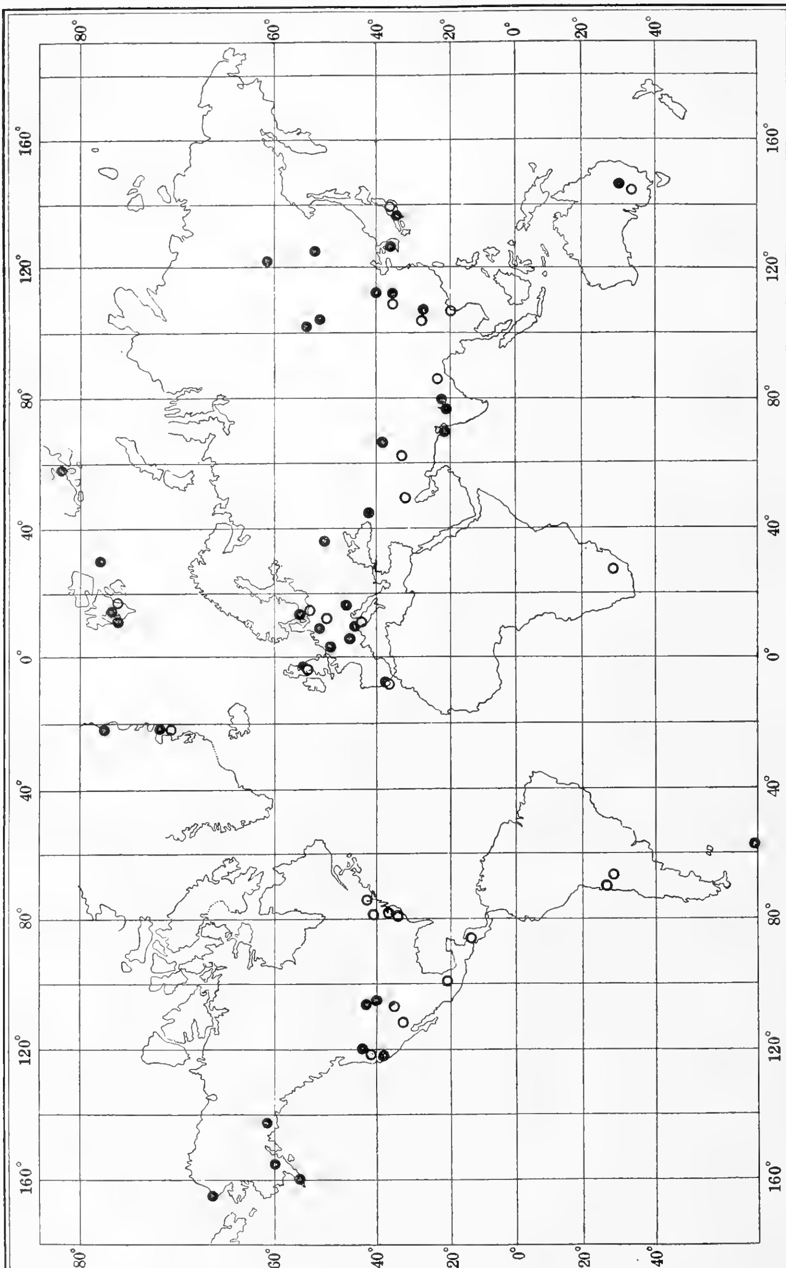

FIG. 1.—Map showing approximate distribution of Triassic and Jurassic floras.

Rings = Triassic
Dots = Jurassic

Austria-Hungary	Steierdorf in Banat
	Crojie in Galicia
	Cracow
Italy	
Switzerland	
Portugal	
Sweden	Bornholm
	Bjuf
Spitzbergen	Cape Boheman, 78° —22′ N.
	Advent Bay, Cape Staratschin
	Green Harbor
King Karls Land	78–79° N.
Franz Josef Land	82° N.
Greenland	Cape Stewart
	80° N.
Siberia	Ust-Balei 51° N.
	Irkutsk
	Upper Armour River
	Lena River District
Corea	
Japan	
Caucasia	
Turkestan	
India	Cutch
	Jabalpur
China	Tyrkyp-Tag
	Border Hami Desert
Australia	
New Zealand	
Louis Philippe Land	63° S.

The flora of the Jurassic, while in the main a continuation of that of the late Trias, and consisting of equisetums, ferns, cycads, ginkgos, and conifers, shows the incoming of a number of more modern types in these groups. The cycads were of course abundant and diversified, whence it has been called the age of cycads. The flora is remarkably uniform over wide portions of the world. Thus not far from 50 per cent. of the North American flora—exclusive of the cycad trunks—is the same as that found in Japan, Manchuria, Siberia, Spitzbergen, Scandinavia, or England, and what is even more remarkable, the plants found in Louis Philippe Land, 63° S., are practically the same as those from Yorkshire, England.

Some idea of the climatic conditions which prevailed at this time may be gained from the present distribution of certain obvious descendants of the Jurassic flora. Thus *Matonidium* and *Laccopteris* are represented by *Matonia* of which there are two species living in the Malay region and Borneo; *Dictyophyllum*, *Protorhipis*, *Hausmannia*, *Caulopteris*, etc., are closely allied to *Dipteris*, which has five species living in the eastern tropics; Ginkgo—so abundant in the Jurassic—has but a single living representative in China and Japan.

Climatic conditions in Jurassic.—The presence of luxuriant ferns, many of them tree-ferns, equisetums of large size, conifers, the descendants of which are now found in southern lands, all point to a moist, warm, probably subtropical climate, though in late Jurassic time the presence of well-defined rings in the tree trunks of species found in northern areas—King Karl's Land, Spitzbergen, etc.—show that there were beginning to be sharply marked seasons.

Wealden.—Immediately above what by common consent is regarded as the top of the Jurassic, is a series of fresh-water plant-bearing beds that are of quite wide extent in this country, though different names have been applied in the different areas. Thus the lower Potomac of the eastern United States (including the Patuxent and probably Arundel), the Glen Rose beds of the Trinity division of Texas, the Lakota and Cloverly of Dakota and Wyoming, the Kootanie of Alberta and adjacent Montana and extending into the Bighorn Basin of Wyoming, and the Shasta of California, and Kome of Greenland are practically equivalent in age, and correspond most closely in age with the Wealden of the Old World, which is considered to be a fluviatile or lacustrine condition of the lower Neocomian, the lowest member of the Cretaceous. The flora is a comparatively rich one, aggregating between two hundred to three hundred species, and is composed of ferns and conifers with a fair sprinkling of cycads Equisetaceae, ginkgos, etc. It shows a considerable agreement with the Jurassic, a number of species being common to the two, but on the whole its affinity is rather with the Cretaceous.

Cretaceous.—Up to the present point in the geological column the most characteristic and dominant feature of the modern flora—namely the angiosperms—has been absent. In many ways the introduc-

tion of this type of vegetation was one of the most important and far-reaching biologic events the world has known. For many years the flora of the Dakota Group and kindred floras was the oldest angiospermous flora known in this country, but as there are such a host of apparently modern types present, it was presumed that they must have had an ulterior period of development—and such proved to be the case. So far as we now know this flora appears to have had its origin in eastern or northeastern North America, in the Patapsco division of the Potomac series. Although the great majority of the plants found in association in these beds, both as regards species and individuals, still belonged to lower Mesozoic types, such as ferns, cycads, and conifers, we find ancient if not really ancestral angiosperms, and many of the same types are found in beds of approximately the same age (that is Albian) at Circal in Portugal. Although we are here much nearer the origin of the angiosperms than was before known, we are probably still some distance from their actual point of origin, but just where or when that was we do not, and may never know.

No sooner were they fairly introduced, however, than they multiplied with astonishing rapidity and in the upper members of the Potomac series—Raritan—they had become dominant, the ferns and cycads having mostly disappeared and the conifers having taken a subordinate position.

By the close of the Comanchan, or Lower Cretaceous, they had spread as far north as Alaska and Greenland, and a large number of modern genera were established.

Climatic conditions during Comanchan.—The climate over this vast area was certainly much milder than at the present time, for such well-known plants as elms, oaks, maples, magnolias, and many others were growing 72° N., in Greenland and nearly as far north in Alaska. It was at least what we would now call warm temperate.

Upper Cretaceous.—With the inauguration of the Upper Cretaceous the angiospermous flora was in full swing.

On the Atlantic border we have the Magothy, which extended from Maryland over New York, Long Island, and as far as Martha's Vineyard. The flora is a rich one, embracing about one hundred and fifty species.

In the interior, in approximately the same position, is the Dakota,

which has afforded a splendid flora of over five hundred species, and occurs in Kansas, Nebraska, Wyoming, Minnesota, along the international boundary, and some of the same forms as far as central Alaska and south to Argentina.

Of the succeeding members of the Upper Cretaceous the Colorado being largely marine has but a small flora, although in southwestern Wyoming there is a small flora, made up mainly of modern types of ferns (*Gleichenia*), that finds its closest affinity in the Upper Cretaceous of Greenland.

Montana.—As this represents alternations of marine with brackish- and fresh-water conditions we have a larger flora, although the total number of known species probably does not exceed one hundred and fifty. Nothing particularly new was established at this time, the genera there being largely of older formations, though the species are mainly different.

Laramie.—As the uppermost member of the Cretaceous series above the marine Fox Hills, the Laramie has had many vicissitudes of interpretation and was made to include beds now known to belong to the Montana, Arapahoe, Denver, Fort Union, etc. As logically restricted to the original definition of King, the plant-bearing Laramie is confined largely to the Denver Basin of Colorado and adjacent areas to the southward, with the probability of its being demonstrated to exist west of the mountains in Colorado, Wyoming, and New Mexico. As above restricted the Laramie flora comprises about one hundred and twenty-five species, and proves to be remarkably distinct from that of the Montana below as well as from the Arapahoe, Denver, and Fort Union above.

Tertiary.—The close of the Upper Cretaceous saw a considerable percentage of the modern angiospermous types of vegetation fully established, not only in North America but throughout the world, and the ferns, cycads, and conifers relegated permanently to a subordinate position. Certain types of dicotyledons, such, for instance, as magnolias, tulip-trees, sassafras trees, etc., had their maximum development in the Cretaceous, and in the Eocene and subsequent stage were greatly reduced until in the modern flora they are often represented by a few or even single species of very restricted habitat. The most noticeable feature of the Eocene flora, broadly considered,

is the increased number of forms that foreshadow the modern flora, a few, indeed, being still living. As examples of the latter mention may be made of the common sensitive fern (*Onoclea*) and two species of hazelnut (*Corylus*) all of which are now living in eastern North America. In late Cretaceous time the sedges (*Cyperus*, *Carex*, etc.) and grasses (*Arundo*, *Phragmites*) had but a poor representation, but in the late Eocene these groups clearly became more numerously developed both in types and species, and thus apparently made possible the rise and development of the mammalia.

Fort Union flora.—The largest and in many respects most important Eocene flora is that of the Fort Union, which is found over a vast area in the central Canadian provinces, north as far as the valley of the Mackenzie River, and south over central and eastern Montana, the western portions of both North and South Dakota, and at many points in eastern and central Wyoming and northwestern Colorado. It has recently been shown by the writer[1] that the Fort Union, extensive as it was known to be, really embraces more than has commonly been assigned to it. Conformably underlying the beds by some geologists considered as the true Fort Union, occur beds which have often been incorrectly referred to the Laramie, or its equivalents, but which are now regarded as constituting the lower member of the Fort Union formation. This lower member, which includes the so-called "Hell Creek beds" and "somber beds" of Montana, and the "Ceratops beds" of Wyoming, and their equivalents throughout much of the area above outlined, contains a rich flora which is inseparably bound to the flora of the upper member.

The flora of the Fort Union considered as a whole embraces more than five hundred species, and comprises ferns, sequoias, cedars, yews, grasses, sedges, oaks, willows, poplars in great abundance and variety, hazelnuts, walnuts, elms, sycamores, maples, a few figs, an occasional palm, and other more modern types. Whatever the conditions under which this flora grew and was entombed, it is beyond question that the climatic conditions were very different from those now prevailing in the region. But for the presence of palms and an occasional fig it might be presumed that the conditions were not greatly different from those now experienced in Atlantic North Amer-

[1] *Proc. Wash. Acad. Sci.*, Vol. XI, 1909, pp. 179–238.

ica, that is, cool temperate. This flora, which is closely similar to that in north Greenland and the valley of the Mackenzie River, undoubtedly approached from the north. The presence of palms, which are found in the lower parts of the formation, argues, on the basis of present distribution, a somewhat warmer climate, just as the numerous thick beds of lignite throughout the formation argue for extensive, long-continued, moister, marsh conditions.

The flora of the lower member of the Fort Union as at present elaborated embraces about eighty-five species of which number about sixty-five are found in the upper member, while only sixteen of the eighty-five species are found in the Cretaceous below. The uncomformity of the base of these beds together with the differences in the flora, clearly and logically marks the point at which the line is to be drawn between Cretaceous and Tertiary.

In the Mississippian region in Louisiana and Mississippi we have a small Eocene flora (Eolignitic) comprising palms, evergreen oaks, magnolias, laurels, cinnamomums, etc., which appear to be most closely affiliated with small floras in northern New Mexico and adjacent Colorado, the latter in turn being most closely related to much larger post-Laramie floras in the Denver Basin of Colorado. These embrace the Arapahoe with about thirty species, and the Denver with nearly two hundred species, and are believed to be slightly older than the Fort Union—in any event, there are only about thirty species in common.

The Green River formation of upper Eocene age occupies a quite extensive area in central and western Wyoming, and has afforded a flora of some eighty species. It is very distinct from the Fort Union and other Lower Eocene floras, and shows a distinct increase of modern forms.

In the northern Pacific coast region there are a number of Eocene floras, among them that of the Swauk which occurs just east of the Cascade Mountains in Washington. This large flora is entirely different from any other in this country, and consists of types that are for the most part found in Central and northern South America, among them being palms 6 feet in diameter and in layers sometimes a foot in thickness. This shows that the palms were not sporadic or occasional, and indicates, as do many of the other things, that the

climate was mild, probably subtropical. The overlying Roslin formation contains a flora that is almost entirely different from that of the Swauk, and lacking the presence of palms was probably slightly cooler than the underlying formation.

To the northward and covering a vast area in Alaska and well out on the Alaskan peninsula is the Upper Eocene Kenai formation which has afforded a rich flora of oaks, poplars, willows, hazels, walnuts, magnolias, horse-chestnuts, and maples, together with pines, spruces, cedars, and sequoias. This flora is found in British Columbia, and abundantly in Greenland, Iceland, and Spitzbergen, showing that it was of wide extent in similar northern latitudes. It is distinctly a warm-temperate flora. Another Upper Eocene flora is found in the Clarno formation of the John Day Basin, Oregon, and in the Payette formation of western Idaho. It embraces walnuts, hazels, birches, alders, oaks, elms, sycamores, maples, ashes, etc., and is temperate or warm temperate, in character.

Eocene floras in the Atlantic area are of very little importance as thus far developed.

Miocene.—The Miocene flora of North America is relatively not a large one although it comprises probably five hundred species as now known. The deposits occur often in isolated basins, widely separated, and there is usually comparatively little in common between them. A number of the more important areas may be briefly mentioned.

At Brandon, Vermont, in the midst of ancient crystalline rocks, occur small pocket-like deposits of lignite which have yielded large numbers of fossil fruits and a very few poorly preserved leaves. The fruits have been studied by Lesquereux, Perkins, and others, and about one hundred and fifty nominal species described belonging to the genera *Nyssa*, *Hicoria*, *Juglans*, *Bicarpellites*, *Cucumites*, *Tricarpellites*, etc.

At Florissant, Colorado, also in the midst of older rocks, there are small lake-bed deposits which have afforded vast quantities of plant and insect material in an admirable state of preservation. The plants number upward of two hundred species, among them being a great number of very modern types and even including not a few herbaceous forms. This flora as a whole is very unlike anything

found in the region at the present day and apparently finds its closest affinity with the West Indies, though doubtless it also approached originally from the north.

Small deposits containing a Miocene flora have been found in Esmeralda County, Nevada, the Similkameen Valley, and other points in British Columbia, and in the Yellowstone National Park. The so-called Muscall beds of the John Day Basin, Oregon, and extending into central Washington, have yielded a rich flora of about eighty species, among them oaks, maples, poplars, barberry, bread-fruit trees, etc., indicating a warm, moist climate. Associated with the auriferous gravels of California is a flora of about one hundred and twenty-five species, some of which are of very modern appearance, such as *Zizyphus*, *Magnolia*, *Persea*, *Acer*, *Artocarpus*, etc.

Pliocene.—The Pliocene flora of North America is almost a negligible quantity, about the only known locality being the Falls of the Columbia River. It includes species in the genera *Woodwardia*, *Sassafras*, *Sterculia*, etc., and is very closely related to living American species.

Pleistocene.—The Pleistocene flora is better known than the last, yet we are undoubtedly only on the borderland of a knowledge of the plants of this period and their distribution. Small Pleistocene floras are known from New Jersey, Maryland, Virginia, West Virginia, North Carolina, Alabama, New York, Iowa, and Canada. The most extensive exploitation of this flora is that made in Canada in the vicinity of Montreal and Toronto, where Penhallow has been able to make out at least three stages. The species are nearly all living.

CERTAIN VALLEY CONFIGURATIONS IN LOW LATITUDES

T. C. CHAMBERLIN AND R. T. CHAMBERLIN
The University of Chicago

To those who have studied the physiographic features of the tropics, the phenomena described in this paper may be quite familiar, but they do not appear to be well known to the average worker in the higher latitudes, and this is our warrant for publishing what at best are but passing notes. If the phenomena have been critically examined by students of tropical physiography it is to be hoped that they may be stimulated by the imperfections of these notes to publish the fuller truth for the benefit of geologists of the mid-latitudes.

In September, 1906, while riding on the Ferrocarril Mexicano from Esperanza on the high plateau down to Vera Cruz on the Gulf, the attention of the writers was caught by the fact that there was practically no talus at the base of the slopes, even when these slopes were steep and rocky. The peculiar configuration of the valley profiles also arrested attention. Further observations made it clear that these features were prevalent. Preliminary to their discussion, it may be remarked that the Mexican plateau has an elevation of some 7,000 feet above the sea. At its eastern border the tableland ends rather abruptly so that the railroad takes advantage of several deep valleys heading back into the plateau and makes frequent windings on their steep slopes to accomplish its descent to the coastal plain. At first tributaries and then the main stream of the Rio Blanco are followed to the city of Orizaba amid impressive scenery. Between Orizaba and Cordoba the railway passes from the valley of the Rio Blanca to the basin of the Rio Atoyac. Beyond Cordoba, the railway line crosses a series of tributaries of the Rio Atoyac through a region of steadily declining relief. The best expressions of the distinctive configuration of the valleys lie in the upper and steeper portions but in some degree they persist throughout.

Above Orizaba the valley slopes are distinctly steep though not strictly precipitous; and yet in favorable localities the stream possesses

a moderate flood plain, giving the valley a measurably flat bottom. It was observed that wherever the valley floor joins the steep valley sides and might be expected to rise into them with a broad free curve, there is instead almost universally a short sharp curve, almost an angle. There is almost no wide open sweep of the surface from the low slope of the bottoms to the steep slope of the valley sides, such as is so common in the mountainous parts of the United States and in higher latitudes generally, so far as we have seen them. In the higher latitudes the foot of a steep slope of indurated rock of this sort is usually buried beneath a belt of talus and mantle rock which serves to merge the high declivity of the valley side by an open concave swing into the low declivity of the valley bottom. In this tropical Mexican valley the slopes are clean and steep all the way down to the immediate vicinity of the flat bottom into which they turn almost at an angle. On the slopes there is only a very scant sheet of mantle stuff adhering to the rock in place, but yet this mantle supports a luxuriant vegetation. The scree slopes, so familiar in like situations in higher latitudes, are almost entirely absent.

In January, 1909, during a brief visit at Honolulu, we were able to make a hasty study of the Nuuanu Valley which leads up the southern slope of the island of Oahu to the Pali, a striking viewpoint on the backbone of the island. Compared with northern configurations, this valley impressed us as unique in its profiles and, while recalling the Mexican phenomena, was not altogether identical with them. The mountain slopes on either side are exceptionally steep, rising when at their maximum with angles of scarcely less than 60°, as near as the eye could measure; and yet they are generally clothed with vegetation, though the bare rock comes to the surface at many points in the midst of the luxuriant vegetal growth. These slopes are well creased by erosion trenches, giving the valley side a corrugated aspect. Except locally, soil is not abundant in the upper part of the valley, even on the bottoms. There appears to be little or no talus at the base of the slopes, which curve sharply into the valley bottom, much as in the Mexican case. The valley bottom presents a general aspect of planeness, but is rough in detail and usually quite rocky.

One of the noteworthy features of the valley is its peculiar cross-

section. It partakes more nearly of the features of a U-shaped glacial valley than of the typical V-shaped valley familiar to geologists as the product of running water at high gradients; but obviously glacial action has had nothing to do with the sculpturing of this valley. It may be exceptional in this feature, which is possibly dependent on differences in the character of the lava that makes up this part of the island. Unfortunately we were unable to visit any of the other valleys of the island. The lack of talus at the foot of the usually steep slopes was notable and in full consonance with the similar absence in the valleys on the eastern border of the Mexican plateau.

On a railway journey from Yokohama to Kyoto, Japan, in latitude about 35° N., the relation of the broad flats of the lowlands to the higher slopes of the uplands attracted especial attention. As in the preceding cases, their junctions were decidedly more abrupt than is usual in like cases in our northern latitudes in America. The first impression received, due no doubt to inherited geologic habit, favored the assignment of the flats to sea work and the abrupt angle they made with the uplands to the girdling of the sea margin. This view, on closer study, seemed probably erroneous. The plains appeared to be aggradation bottoms, in the main, built up or at least sheeted over by the numerous rivers that emerge from the mountains. The streams across them have notable gradients. The abruptness is thus probably in part constructive, rather than erosional, but is probably also in part erosive and perhaps of the Mexican type.

In South China features of an analogous order were noted. The Si Kiang, or West River, has a long course through the moderately mountainous country which is characteristic of Southern China. From the bottoms that adjoin the river, the hill slopes usually rise promptly and steeply. The mountain range west of Sam Shui in the province of Kwang Tung was estimated to reach 1,000–1,200 feet and perhaps at points 1,500 feet in elevation. Very little talus was seen on its slopes or on any of the mountain slopes. The soil is thin, and under the climatic conditions prevailing here the hills have a limited vegetal covering and are very scantily cultivated. There are, however, lower hills that are often well rounded, with clean, smooth slopes.

From the town of Wuchow in the province of Kwang Si an ascent of a prominent peak, 1,200 feet above the town, gave a commanding view of the general topography of the country about the junction of the Si Kiang and Kwei Kiang. The erosion of this region, working upon an older elevated peneplain of undetermined geologic date, has been very pronounced. Almost everywhere sharp V-shaped valleys with very straight, even-sided slopes prevail. There is practically no talus or aggradation accumulations until the river level is approached.

FIG. 1—Bowlders of exfoliation near Kowloon on the Asiatic mainland opposite Hong Kong.

In contrast to the above, among the White Cloud hills near Canton, in Kwang Tung, there are extensive accumulations of arkose material. In fact, the solid rock, which is of the granitic type, is almost everywhere buried beneath its own disintegrated products. A similar condition in even more pronounced form was observed at Kowloon on the Asiatic mainland, opposite Hong Kong. In many of the cuts for the new railroad now being constructed from Kowloon to Canton

many feet of disintegrated material were found above the more indurated granite into which the arkose graded slowly. This granite in its upper portion is soft and partially disintegrated. In its lower portion certain "bowlders" or less disintegrated portions in it were being quarried for building purposes. It was not altogether clear whether the "bowlders" are to be regarded merely as residual remnants of a once homogeneous mass left by the unequal progress of disintegration, or whether the whole was a secondary deposit of mixed arkose and bowlders derived from the adjacent hills and once partially cemented together, but which has more recently again resumed its disintegration. There are some reasons for believing that both alternatives are true in different portions of the district. In those localities where deep disintegration prevails, the upper slopes merge into the lower slopes in the gradual, curving way common in higher latitudes.

The main purpose of these notes is to lay emphasis on the relatively sharp angle between the valley sides and the valley bottoms observed in several of these regions of low latitude. In part this feature may, no doubt, be said to be due to the comparative absence of talus at the foot-slope of the valley sides, but this is probably not the whole truth of the matter. The relative absence of coarse talus of a certain kind in low latitudes is recognized as assignable to the absence of freezing temperatures by virtue of which the repeated expansion of water in joint planes, cracks, and pores disrupts the surface rocks and loosens masses which roll to the foot of the slope.[1] The localities named in this paper, except that in Japan, are all within the border of the tropics and this explanation is applicable so far as it goes. Talus piles and scree slopes of the frost type are obviously excluded by the climatic conditions. Bowlders due to exfoliation, which we found so abundant at Kowloon, are probably absent in the localities characterized by thin soils because in these cases the decay proceeded more uniformly and slowly from the surface and was more largely confined to the surface instead of penetrating deeply along the joints and working from them toward the centers of the blocks between the joints. This limitation of action was probably due in turn to the close texture of the rock in the Mexican, Oahu,

[1] J. C. Branner, "Decomposition of Rocks in Brazil," *Bull. G. S. A.*, Vol. VII, 1896, p. 268.

and Kwang Si cases. In the Canton and Kowloon cases granular disintegration prevailed in a marked degree, as is well known to be common in low latitudes, but in these cases the rock was granitic and peculiarly susceptible to this mode of disaggregation. In the Mexican and Oahu localities the rocks were mainly close-textured lavas; in Kwang Si fine-grained sediments, in the main. Under the influence of a warm climate, aided by the tropical vegetation, the rocks of these localities seem to pass into soil on the surface with little detachment of blocks, bowlders, or other coarse material. The rains of these regions are sufficient to keep the soil thin in spite of the vegetal protection and thus to keep the decay working actively on the whole outer surface.

While this seems to explain the nature of the surface and the thin surface mantle, we are not fully persuaded that it altogether explains the abruptness of the change from the side slopes to the valley bottoms. Without attempting to give very cogent reasons for the interpretation, we are disposed to refer this to a mode of hydraulic action which is really normal but which seems abnormal to us because in mid-latitudes it is commonly thwarted by an overburden of detritus. During a rain the water on the slopes grows in amount as the slope is descended and the wash-action is normally greatest at the foot of the slope if the water has not become overloaded with detritus in its descent. The velocity of flow also increases as the slope is descended and this further adds to the erosive power toward the base of the slope. A normal slope should therefore approach more and more to the vertical as it gains in descent. This is almost universally true of the brow and upper part of the slope in all latitudes. Why does it not persist to the bottom? In certain cases it does. Certain mesas, buttes, and outliers, particularly in arid lands, possess essentially vertical sides which reach down either to coarse talus piles or to the horizontal beds of the surrounding region. In some instances there is sapping at the base due to more perishable layers but in other cases there is no sign of this and the cutting at the base appears to be due to the superior volume and velocity of the water rushing down the sides. In these cases the effect is probably correlated with the absence or scantiness of vegetation which when present restrains the rush of the waters. A similar effect is shown in waterfalls, though here differ-

ences of rock resistance usually overshadow it and the joint result has an abnormal expression. Erosion is markedly greatest at the foot of the falls where deep excavation and undercutting are pronounced. A better case for the present comparison is the development of rapids and cascades into vertical falls by the greater erosion at the base of the plunge, even in cases where the rock is essentially homogeneous.

In all these cases the superior erosion due to superior velocity or volume or both is carried only to a certain extent because it meets restraint in the supporting effects of the neighboring rock, and this is probably the key to the solution of that balance of effects seen at the foot-slopes of valleys. While the floods from the slope increase in volume and velocity all the way down the steeper part of the slope, and considered by themselves alone should increase the slope even to verticality, the flat-lying rocks of the valley bottom lend support to the foot of the slope by giving a less proportion of exposure and a higher ratio of adhesion to its surface parts and thus render their removal less easy than they would be in the absence of such support. If this is not quite obvious it may perhaps become clear on picturing a vertical wall formed of spherical granules meeting a horizontal surface of like kind at right angles and noting the individual conditions of the granules. If A represents a granule at the angle, $BB'B''$, etc., the successive granules above it in the face of the vertical wall and $CC'C''$, etc., the successive granules in the horizontal face, it is clear that A will be least easily removed because only 90° of its circumference is exposed while 270° is both protected and attached, whereas 180° of the circumference of the B and C granules is exposed and only 180° protected. With equal wear the B and C granules must suffer most and the angle gradually pass into a curve. In a similar way it may be seen that the granules that form a short concave curve are less exposed and have more attachment than the granules of a more open concave curve, or of a plane or convex curve. Each portion of the slope is thus dependent, in a measure, on the support of the other portions and the flat portion of the valley bottom may be said to support the rock at, and near, the angle and cause the development of a curve which represents the working balance between the agencies of erosion and of resistance. By this curve the increasing flood from the slope is

gradually turned from its nearly vertical descent into a more nearly horizontal course.

The meaning of the short curve as distinguished from a longer curve lies in the balance of the co-operating agencies. A good mantle of vegetation when present measurably restrains the plunging waters and somewhat softens the curve of transition. In the absence of vegetation, the abrupt mesa-cliff on the one hand and the vertical or even overhanging falls on the other are liable to develop. The abrupt curve at the foot-slope in the tropical cases described is thus referred to a co-operation of agencies in which (1) the absence of talus-making causes, (2) the prevalence of minute surface decay, (3) the restraint of vegetation, and (4) the concentration of the wash toward the foot-slope are conjoined. This phase of action seems to be prevalent in low latitudes, but not equally so in high latitudes.

THE ANTHRACOLITHIC[1] OR UPPER PALEOZOIC ROCKS OF KANSAS AND RELATED REGIONS

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A recent monograph by Dr. George H. Girty[2] contains certain statements which are so misleading that I desire to briefly call attention to them. In the main they refer to some remarks of mine[3] concerning earlier conclusions published by Dr. Girty relating to the age of the Guadalupian and its correlation with the Upper Paleozoic formations of Kansas.

Dr. Girty has attributed a threefold argument to me[4] which he then proceeds to take up in detail.[5]

In regard to the age of the Guadalupian which is his first point, I quoted *exactly* the words used by Dr. Girty in his two papers and gave them in the order in which they were published.[6] In no way did I attempt to obscure his meaning or mislead the reader concerning it. I *did note* that he had changed quite decidedly from his first opinion concerning the age; but I made no comment and in no way attempted to criticize his opinions. His statement in this last work that I am correlating the Guadalupian with the Upper Permian is erroneous, for I have never expressed *any* opinion concerning the age of the Guadalupian.

In the second place I compared the lists of fossils from the Hueco and Kansas formations published at that time by Dr. Girty, as I

[1] The Anthracolithic is a term proposed by Waagen for the united Carboniferous and Permian systems (*Palaeontologia Indica*, Ser. XIII, Vol. IV, "Geological Results," p. 241). It is here used when speaking of the Carboniferous and Permian systems taken together or as an equivalent of the somewhat indefinite term of Upper Paleozoic.

[2] "The Guadalupian Fauna," *United States Geological Survey, Professional Paper 58*, 1908 [1909].

[3] *Am. Geol.*, Vol. XXXVI, 1905, pp. 156–58.

[4] "The Guadalupian Fauna," *op. cit.*, p. 40.

[5] *Ibid.*, pp. 40–42.

[6] See pp. 156 and 157 of my paper.

stated in my article, and failed to find a single listed species common to the Hueco and Marion formations, the latter occurring next above the Chase stage in Kansas. His statements concerning the correlation between the Kansan and Texan formations I understood to be founded upon paleontologic evidence and my remarks were based simply upon an examination of such published evidence.

In regard to the third point it is true that I understood Dr. Girty's statement in 1905 to refer to the *time* of the deposition of the Capitan, Kansas deposits, and Permian, but as he now explains it he intended to refer especially to their *terminology*. So far as terminology is concerned, as I now understand Dr. Girty and the facts, I should say that the term Guadalupian series essentially as Dr. Girty originally proposed it, *except* that he gave it as "Guadalupian period,"[1] would, for the present at least, be used for the Texan deposits. In Kansas the Upper Paleozoic deposits are known under the names of the Big Blue and Cimarron series. If the Big Blue, Cimarron, and Guadalupian series were deposited during Permian *time* I see no serious objection to putting them in the Permian *period* or system, recognizing this division as co-ordinate in rank with the Carboniferous and other periods of the Paleozoic in accordance with the usage of the majority of geologists who have carefully considered the classification of the Upper Paleozoic. Later studies may show more accurately the relationship of the Texan and Kansan series and make necessary changes in the local classifications. Dr. Beede has suggested the quite different conditions under which these two faunas lived, stating that "one is a cosmopolitan, open-sea, coastal shelf fauna while the other is a more isolated epicontinental sea fauna rather thoroughly separated from its neighbor on the south and perhaps belonging to a different climatic zone."[2]

The assumptions, in connection with the three points noted above, which appear in the work under discussion, I am not responsible for, and therefore they require no further notice.

The expression "Kansas 'Permian'" appears very frequently in the Introduction to "The Guadalupian Fauna" and often it

[1] *Am. Jour. Sci.*, 4th ser., Vol. XIV, 1902, p. 368.

[2] *Jour. Geol.*, Vol. XVII, p. 678.

is used as though it were equivalent to the series of formations for which I have used the designation of Permian system. At this place it is well to state that, so far as terminology is concerned, I consider the Permian division as having the rank of a *period* in time (*system* on the rock scale), and not that of an *epoch* (*series* on the rock scale), in accordance with the usage of most of the recent leading American and European standard manuals of geology.[1] In certain papers published by the United States Geological Survey or with its permission I have used the name Permian with the taxonomic rank of an *epoch* or *series*, because required to do so by the rule of the United States Geological Survey which states that "in the Carboniferous, Permian, Pennsylvanian, and Mississippian" are series "now recognized as applicable to North America."[2] Dr. Girty uses the term "Permian epoch"[3] in accordance with the rule of the United States Geological Survey. If this fact be kept in mind it will explain some of the differences in correlation between the papers of Dr. Girty and my own.

Concerning the lower limit of the Permian system in Kansas I wrote in 1895:

> If it be considered better to put all the beds in either the Carboniferous or Permian system, it might be just as well to refer the deposits generally called Permo-Carboniferous to the Permian. If such correlation be agreed upon, then, in Kansas, the line separating the Cottonwood and Neosho formations would become the line of division between the Carboniferous and Permian systems.[4]

Furthermore, on pp. 795, 796 I continued as follows:

> Consequently we would refer the Wabaunsee and Cottonwood formations to the Upper Coal Measures. The Neosho and Chase formations are transitional

[1] See Chamberlin and Salisbury, *Geology*, Vol. II, 1906, p. 619; Scott, *An Introduction to Geology*, 2d ed., 1908, p. 637; Geikie, *Text-Book of Geology*, 4th ed., 1903, Vol. II, p. 1063; De Lapparent, *Traité de géologie*, 5th ed., Vol. II, 1906, p. 752; Suess, *The Face of the Earth* (*Das Antlitz der Erde*), Sollas' translation, Vol. II, 1906, p. 249 (*La Face de la terre*, Margerie's translation, Tome II, 1900, p. 407); Kayser, *Lehrbuch der Geologie*, 3d ed., II. Teil, 1908, p. 256; Credner, *Elemente der Geologie*, 9th ed., 1902, pp. 367, 490; Dannenberg, *Geologie der Steinkohlenlager*, erst. Teil, 1909, p. 42; Toula, *Lehrbuch der Geologie*, 1900, pp. 200, 231; Neumayr, *Erdgeschichte*, Vol. II, 1890, p. 199; Frech in *Lethaea geognostica*, Theil I, "Lethaea palaeozoica," 2. Bd., 3. Lief., 1901, p. 453; Koken, *Die Leitfossilien*, 1896, p. 550.

[2] *Twenty-fourth Ann. Rept.*, 1903, p. 27.

[3] "The Guadalupian Fauna," *op. cit.*, p. 42.

[4] *Jour. Geol.*, Vol. III, p. 793.

from the Upper Coal Measures to the Permian, as first defined by Murchison for Russia, and belong to the division which has generally been called Permo-Carboniferous, in this country. In accordance with the views of the majority of present European geologists familiar with this problem it is probably better to include the Permo-Carboniferous rocks of Kansas in the Permian series. . . . . The Marion formation belongs to the undoubted Permian and contains only fossils which are characteristic of that series.

In Russian geological literature the term Permo-Carboniferous frequently occurs, the lower terrane of which is the Artinsk and the upper the Kungur; but the later standard European works on geology refer these terranes to the Permian.[1] I have followed them in putting the Kansas Permo-Carboniferous in the Permian. Dr. Kayser in the last edition of his *Formationskunde* states that the Permian formation of the interior Russian-Uralian district is divided in the following manner:

Tartarian stage Russian Zechstein (limestone) Kupfer sandstone Lower Red Beds	Permian in the strict sense.
Kungur stage Artinsk stage	Permo-Carboniferous of Russian geologists.[2]

Dr. Kayser has written me recently that:

As far as the Artinsk formation is concerned, I still entertain the same opinion as at the time of the writing of the last edition of the *Formationskunde*, i. e., I look upon it as the *base of the Permian*. The Ammonite fauna of the Artinsk, which varies considerably from the Carboniferous, and the flora seem to me in this respect decidedly significant.[3]

The line of division between the Carboniferous and Permian I always considered a debatable one. In my paper of 1902 it was thought that the evidence favored drawing it at the top of the Neosho member of the Garrison formation or at the base of

[1] Geikie, *Text-Book of Geology*, 4th ed., Vol. II, 1903, p. 1077; De Lapparent *Traité de géologie*, 4th ed., Vol. II, pp. 968, 993; Kayser, *Lehrbuch der Geologie*, 3d ed., pt. II, 1908, p. 290; Frech, *Lethaea geognostica*, Theil I, "Lethaea palaeozoica," 2. Bd., 2. Lief., 1899, chart opposite p. 394, and 3. Lief., 1901, pp. 493–99; Credner, *Elemente der Geologie*, 9th ed., 1902, p. 517; Toula, *Lehrbuch der Geologie*, 1900, pp. 219, 238.

[2] *Lehrbuch der Geologie*, Pt. II, 1908, p. 290.

[3] Letter of November 11, 1909.

the Wreford limestone of the Chase stage.[1] This agreed quite closely with the later correlation of Dr. Tschernyschew who drew the line separating the homotaxial equivalents of the Russian Upper Carboniferous and Permo-Carboniferous at the base or in the lower part of the Chase stage. The following is a translation of Dr. Tschernyschew's views: The Neosho beds, and possibly also the lower part of the Chase, appear analogous to the Russian Schwagerina horizon [the Schwagerina beds form the upper division of the unquestioned Upper Carboniferous of Russia, just below the Artinsk] and the remainder of this, as well as the Marion beds, one must consider as homotaxial with the Russian Permo-Carboniferous and lower Permian. Finally, the Wellington and Cimarron beds may correspond to the lower red-colored Permian in eastern and northern Russia.[2]

More accurate information concerning the horizon of certain vertebrates described by Dr. Williston from southern Kansas led the writer in 1907 to suggest that perhaps the Cottonwood limestone at the base of the Garrison formation, which is nearly the same as the first provisional line, "is really nearer the line of division between the Pennsylvanian and Permian than the Wreford limestone at its top."[3] This line is from 140 to 145 feet lower than the base of the Wreford limestone and about 14 feet lower than the line suggested in my first paper on the classification of these rocks in 1895.[4]

When my earlier papers were written no fossils had been found in the Cimarron series or Red Beds and in 1897 I stated that "the correlation of these rocks with either the Triassic or Permian is a matter of uncertainty."[5] In 1906 Doctors Gould and Beede published an account of the discovery of Permian fossils in a sandstone west of Alva, Oklahoma, the stratigraphic position of which was given

[1] *Jour. Geol.*, Vol. X, Chart of "Classification of the Upper Paleozoic Formations of Kansas," opp. p. 718.

[2] *Mém. comité géologique*, Vol. XVI, No. 2, 1902, pp. 392, 393 of Russian text and p. 703 of German text. For translation see *Am. Geol.*, Vol. XXXVI, 1905, p. 154, and Schuchert in *Am. Jour. Sci.*, 4th ser., Vol. XXII, 1906, p. 38.

[3] *Jour. Geol.*, Vol. XV, p. 823.

[4] *Ibid.*, Vol. III, p. 800.

[5] *Univ. Geol. Surv. Kansas*, Vol. II, p. 92.

as in the Red Bluff sandstone[1] which occurs well toward the top of the Cimarron series as found in Kansas. Finally, in 1907, Dr. Beede described a fauna from Dozier, in the Panhandle of Texas, which occurs stratigraphically, according to Doctors Beede and Gould, in the Quartermaster division of the Oklahoma formations which they state "is the highest formation in the Red Beds, and the fossils came from well up in this formation."[2] According to these geologists the Quartermaster division occurs entirely above the top of the Cimarron or Red Beds as found in Kansas. Dr. Beede described the faunas from the Whitehorse sandstone and the Dozier beds under the title of "Invertebrate Paleontology of the Upper Permian Red Beds of Oklahoma and the Panhandle of Texas" and said:

> These collections are of great importance, as they furnish the final evidence that the Red Beds, below the Dockum beds, of the Oklahoma-Panhandle region are Paleozoic in age. . . . . The faunas are somewhat heterogeneous as to origin. Some of the species seem to be directly derived from the Kansas Permian or Pennsylvanian, while others, as pointed out in the discussion of the species, are derived from the European Permian, especially that of Russia.[3]

In the lower part of the Enid division at a horizon corresponding with the upper part of the Wellington shales of Kansas,[4] which is the highest formation of the Big Blue series, near Nardin and Orlando, Oklahoma, vertebrate fossils were found. The specimens from Orlando were studied by both Doctors Williston and Case and a preliminary list was furnished by Dr. Williston who wrote Dr. Gould as follows concerning it: "Altogether you see that these fossils point unmistakably to the Permian."[5] Dr. Case furnished a report on these fossils for publication and in conclusion said:

> The result of the determination of these fossils has been to settle the long mooted question of the age of the Red-beds. . . . . The Red-beds of Oklahoma,

[1] Beede, *Am. Geol.*, Vol. XXVIII, July, 1901, pp. 46, 47. The fauna was first described by Dr. Beede in the "Advance Bulletin of the First Biennial Report of the Geological Survey of Oklahoma," April, 1902. Later it was more fully described by the same author in the *Kansas Univ. Science Bulletin*, Vol. IV, March, 1907, pp. 115–72, Pls. V–IX; Gould, *Jour. Geol.*, Vol. IX, July, 1901, pp. 337–41.

[2] *Kansas Univ. Science Bull.*, Vol. IV, p. 141.

[3] *Ibid.*, pp. 115, 142.

[4] Beede, *Kansas Univ. Science Bull.*, Vol. IV, 1907, p. 138; Gould, *Jour. Geology*, Vol. IX, 1901, p. 339.

[5] *Sec. Biennial Rept.*, Dept. Geol. and Nat. Hist., Territory of Oklahoma, 1902, p. 60.

then, or at least the members as high as the Greer formation [the base of which is near the top of the Kansas deposits] are of Permian age.[1]

Fossil plants were collected in the Wellington shales[2] in the southern part of Dickinson County, which were studied by Dr. Sellards who wrote as follows concerning them:

> There are, in the collections so far made, some twenty-six or twenty-seven determinable species, distributed in fourteen genera. The plants indicate unmistakably the true Permian age of the formation in which they are found. Many of the species are characteristically Permian, and only a very small proportion of the species identical with Upper Carboniferous species.[3]

Part of this material was communicated to the National Museum by Dr. Sellards and examined by Mr. David White of the United States Geological Survey, who wrote as follows regarding it:

> If the composition of the entire flora proves to be of so young a character as the material described or placed in my hands by Mr. Sellards, his conclusion that the beds are of so late date as the Lower Permian will appear to be fully justified. . . . . However, such pteridophytic material as has come to me for examination is more nearly typical and characteristic of the Permian than any flora that I have yet seen from another formation in the United States. If the plants preliminarily listed above are representative of the plant life of the Upper Marion or the Wellington formation, the flora of these beds is probably of a date fully as late as the earlier of the floras generally referred to the Permian in western Europe. In any event a flora containing these species can hardly be older than the topmost Carboniferous, or transitional from the Upper Carboniferous to the Permian.[4]

In January, 1903, Dr. Sellards wrote me as follows:

> The fossil plants in my opinion support your belief in the existence of true Permian in Kansas (below the Red Beds). The flora of the Marion (or Wellington) differs specifically almost *in toto* from that of formations as low down as the Lawrence shales [which occur in the Pennsylvanian near the top of Professor Haworth's Douglas stage] and indicates as I have already stated (*Kans. Acad. Sci.*, 1900; *Kans. Univ. Bull.*, Vol. IX, Jan., 1900) a lower Permian age. The plants in this case are pretty conclusive and the genera and species are identical with or most closely related to those of the lower Permian of Europe.[5]

[1] *Ibid.*, p. 68.

[2] Stratigraphic identification by Dr. J. W. Beede, see *Am. Jour. Sci.*, 4th Ser., Vol. XXVII, 1909, p. 169.

[3] *Trans. Kansas Acad. Sci.*, Vol. XVII, 1901, p. 209.

[4] *U. S. Geol. Surv., Bull. 211*, 1903, p. 117.

[5] Letter of Jan. 12, 1903, and see *Am. Geol.*, Vol. XXXVI, p. 149.

Dr. Sellards also found well-preserved insects associated with the plants in the Wellington formation of Dickinson County which he contrasted as follows with those from near Lawrence, Kansas:

> The insects from the Marion seem on the whole very different from those of the Lawrence shales and other Coal Measure deposits. . . . . These collections [of fossil plants from the Wellington] have since been increased and it may now be said with a good deal of confidence that, although a few species have survived from the Upper Coal Measures, the Marion [Wellington] contains on the whole a distinctly Permian flora. The marked change in the insect fauna in passing from the Lawrence shales to the Marion [Wellington] formation is therefore paralleled by the plant evolution.[1]

This fairly full summary of the conclusions of the various paleontologists who have carefully studied the fossils from the deposits under consideration in Kansas and Oklahoma, previous to the publication of my last note on this subject in December, 1907,[2] is given in order to show the limits of the Permian as indicated by fossils and that, with the exception of Dr. Girty,[3] all agreed in referring them to the Permian. It is believed by the writer that the above evidence warrants the provisional correlation of these Kansas deposits with the Permian, until it is shown by someone that such correlation is erroneous, and that the Permian system extends to the top of the Cimarron series or Red Beds as found in Kansas. References to and quotations from the works of various European geologists who have correlated these deposits with the Permian have been given in earlier publications. Finally, it is to be noted that the fossil evidence now in hand indicates that the base of the Permian system in Kansas begins as low as the Cottonwood limestone, or perhaps a little lower, and that the succeeding rocks in Kansas to the top of the Red Beds belong in this system, *because* still higher deposits to the south in Oklahoma and the Panhandle of Texas contain a Permian invertebrate fauna as described by Dr. Beede. The above-defined deposits are those which I call the Permian system and for which I have accepted the division into two series, viz., the Big Blue and Cimarron, proposed by Professor Cragin in 1906.[4]

[1] *Am. Jour. Sci.*, 4th ser., Vol. XVI, 1903, pp. 323, 324.

[2] *Jour. Geol.*, Vol. XV, p. 822.

[3] *Ibid.*, Vol. X, 1902, p. 723; *U. S. Geol. Surv., Bull. 211*, 1903, pp. 74–77.

[4] *Colorado College Studies*, Vol. VI, March, 1896, pp. 3, 5, 18.

Dr. Girty states:

> In the first place, here and elsewhere in speaking of the Kansas "Permian" I refer to the Chase and Marion formations, but not to any of the higher beds, as I believe that the only practical method of correlating terranes so widely separated as those of Kansas and Russia is by paleontologic evidence; and since the evidence of invertebrate paleontology only is that which I am in a position to understand and weigh, it is natural that any statement of mine must apply to that portion of the Kansas section where invertebrate fossils are found, and cannot consistently apply to formations overlying the Marion, where invertebrate evidence appears to be absent. Furthermore, unless otherwise indicated, in speaking of the Permian I refer primarily to the Russian Permian exclusive of the underlying Artinsk or Permo-Carboniferous.[1]

It will be seen on comparison with what I have given above that according to Dr. Girty's definition what he has discussed as the "Kansas Permian" includes only a *part* of the deposits which the Kansas geologists refer to that system. In other words, it does not fully represent the Big Blue series and none of the Cimarron series is included; consequently this fact should be kept in mind when considering what he has said in reference to the "Kansas Permian." The horizons at which the invertebrate fossils were found in Oklahoma and northern Texas have been accurately fixed in relation to the Kansas deposits by stratigraphic work from Kansas to Texas, so that the consideration of their faunas is entirely appropriate in determining the age of the Kansas deposits. The Whitehorse sandstone fauna was known to Dr. Girty at the time he wrote this monograph, since he refers to it on p. 48.

There is a difference of opinion among European geologists as to whether the Artinsk, which is the lower division of the Permo-Carboniferous of the Russian geologists, should be included in the Permian. I have always recognized this fact; but it has appeared to me that the usage of the majority of those best acquainted with the subject favored its reference to the Permian. An extract from the work of Dr. Carl Diener, the accomplished professor of paleontology in the University of Vienna, who has so fully described the Permo-Carboniferous and Permian of the central Himalayas of India, and who has clearly stated the views of the two noted Russian geologists who favor the separation of the Permo-

[1] "The Guadalupian Fauna," *op. cit.*, pp. 46, 47.

Carboniferous from the Carboniferous and Permian systems, is important in this connection:

Karpinsky and Tschernyschew, two authors, to whom the most detailed studies of the Artinskian fauna are due, strongly advocate the distinction of the permocarboniferous from carboniferous and permian systems, and are decidedly averse to uniting it with either the one or the other. Tschernyschew especially strongly combats the view of the majority of geologists who proposed to unite the permocarboniferous with the permian, as a lower division of the system. According to him a separation of the permocarboniferous from the permian system is demanded by the general aspect of the fauna, in which the carboniferous types greatly predominate, chiefly among the brachiopoda. If it ought to be united either with the carboniferous or permian system, in spite of its distinctly intermediate position, it must necessarily be placed in the former, on the strength both of the carboniferous character of its fauna and of historical priority, since the Artinskian sandstone had been correlated with the carboniferous millstone-grit of western Europe by Sir Roderick Murchison, who first introduced the name of permian.

Against the first argument the objection may be raised that notwithstanding the prevalence of carboniferous types in the Artinskian fauna, the latter "marks a very important moment in the history of development of organic remains, namely, the first appearance of true ammonites with complicated sutures." Nor is the large percentage of carboniferous types in the Artinskian fauna an astonishing fact, in view of the absence of any break in the sequence of marine beds from the upper carboniferous to the true permian strata. . . . . Bearing in mind the gradual passage from an upper carboniferous to a permian fauna through the intermediate group of rocks, the question to be answered is, which consideration is of the greater importance in defining the boundary between the two systems, the appearance of a new group of cephalopoda, which become of an unparalleled stratigraphical value in Mesozoic times, or the presence of a belated fauna, composed of forms which are generally not well adapted for the characterization of narrowly limited horizons.

The majority of geologists have decided in favor of the first alternative. Gümbel, Krasnopolsky, Kayser, Waagen, Credner, Munier-Chalmas and A. de Lapparent, Frech—to enumerate only a small number among them—are unanimous in regarding the permocarboniferous as the lowest division of the permian system.

A discussion of the permocarboniferous problem from a historical point of view leads to a similar result. This side of the question has been especially treated by Frech, whose reasoning I consider to be entirely justified.[1]

[1] "The Permocarboniferous Fauna of Chitichun," No. I, *Mem. Geol. Surv. India*, ser. XV, "Himálayan Fossils," Vol. I, Pt. 3, 1897, pp. 87–89. This quotation may also be found in an article by Professor Schuchert in *Am. Jour. Sci.*, 4th ser., Vol. XXII, 1906, pp. 143, 144.

Dr. Diener's account of the correlation of the Upper Paleozoic formations of central Europe with those of Russia is also interesting. The professor wrote as follows:

In the Rhenish regions, where the sequence of terrestrial and lacustrine plant-bearing strata of this epoch is most complete, the true coal measures come to an end with the Ottweiler Schichten, whereas the following series of rocks, comprising the Cuseler and Lebacher Schichten, have been united in a lower division of the permian system by Gümbel. In the Carnian Alps plant-bearing beds, containing a rich flora of the Ottweiler Schichten, alternate with Fusulina limestones, which have been proved by Schellwien to be homotaxial with Nikitin's Gshelian stage in Central Russia. As has been noticed by Geyer, this alternating series of dark Fusulina limestones and plant-bearing beds is conformably followed by a compact mass of white Fusulina limestones (Trogkofelkalk) containing *Spirifer supramosquensis* Nikitin, which must be correlated with the topmost carboniferous Fusulina limestones (Schwagerina horizon) of the Ural Mountains. The homotaxis of the Ottweiler Schichten and of the Carnian Fusulina limestone, which itself corresponds in age to the uppermost carboniferous beds of Central Russia (Gshelian stage) and of the Ural (Cora horizon, and Schwagerina horizon), apparently requires the boundary line between the two systems to be drawn immediately above the Schwagerina limestone of the Ural and Timan, and below the Artinskian stage.[1]

Professor Diener still believes that the Artinsk belongs in the Permian, as may be seen in the following quotation from a recent letter:

The Artinskian stage of Russia I still consider as forming the lowest stage of the permian system. Its cephalopod fauna differs decidedly from any which has been found in the upper carboniferous rocks of the Ural. As a boundary line must necessarily be drawn between the two systems, this line—artificial as it is—should be drawn at the base, not at the top of the Artinskian stage.[2]

In all my references, however, to the correlations of the Kansas deposits with those of Europe by European geologists, I have given exactly the name of the European division with which they made correlation and if it were with the Artinsk or Permo-Carboniferous it was so stated.

On page forty-eight Dr. Girty states that "Tschernyschew correlates part but not all of Prosser's 'Permian' with the Artinsk"; while on the following page he says, "if the Kansas 'Permian'

[1] *Ibid.*, p. 89.

[2] Letter of November 24, 1909.

is Artinsk, as Tschernyschew believes." The translation of Dr. Tschernyschew's statement is as follows:

The Neosho beds and possibly also the lower part of the Chase, appear analogous to the Russian Schwagerina horizon and the remainder of this as well as the Marion beds one must consider as homotoxial with the Russian Permo-Carboniferous and lower Permian. Finally, the Wellington and Cimarron beds may correspond to the lower red-colored Permian in eastern and northern Russia.[1]

The following correlation table of the Russian and American formations, omitting the column for California, Nevada, Utah, and Colorado, follows Dr. Tschernyschew's general discussion of these deposits:[2]

Ural and Timan	Texas and Arkansas	Kansas, Nebraska, Iowa, Missouri
Artinsk deposits	Wichita and Clear Fork beds	Marion Beds Chase beds
Schwagerina horizon	Albany and Cisco beds	Neosho beds
Cora horizon	Canyon and Strawn beds	Missouri series and Cottonwood beds of Kansas and Nebraska Wabaunsee beds Oread limestone and Osage shales of Kansas
Omphalotrochus horizon		Series from the Garnet to the Oswego limestones in Kansas. Des Moines beds in the state of Missouri

It is to be remembered that Dr. Tschernyschew believes in the separation of the Permo-Carboniferous from the Carboniferous and Permian systems. He places the Artinsk in the Permo-Carboniferous and directly overlying the Artinsk is the dolomitic limestone (Kungur) the base of which marked the lower limit of Murchison's original Permian, according to some authors, while others make its top the base. The Permo-Carboniferous of the Russian geologists is generally

[1] *Mém. comité géologique,* Vol. XVI, No. 2, 1902, p. 703. The original is as follows: "Die Neosho-Schichten und vielleicht auch die untere Partie der Chase-Suite erscheinen dem Schwagerinen-Horizonte Russlands analog und der Rest von dieser, sowie die Marion-Schichten muss man als dem russischen Permo-Carbon und unterer Perm homotaxal ansehen. Die Wellington- und Cimarron-Schichten endlich dürften der unteren roth gefärbten Perm-Suite im Osten und Norden Russlands entsprechen."

[2] *Ibid.*, p. 395 of Russian and 706 of German text.

composed of the Artinsk (CPg) and the superjacent dolomitic limestones (CPc).

Hans v. Staff has recently published the following table of the Russian Upper Carboniferous *Fusulina*-bearing horizons:[1]

<table>
<tr><th>Permo-Carboniferous</th><th>CPg[1]</th><th colspan="2">Arta [Artinsk] stage</th><th>Lower Rothliegende</th><th>Lower Dyas</th></tr>
<tr><td rowspan="4">Upper Carboniferous</td><td>$C\tfrac{3}{3}$</td><td colspan="2">Schwagerina horizon</td><td>Horizon of Schwag. princeps</td><td>Upper upper Carboniferous</td></tr>
<tr><td>$C\tfrac{2}{3}$</td><td>Cora horizon</td><td rowspan="3">Omphalotrochus horizon (Bed of Gshel)</td><td rowspan="3">Bed of Spirifer supramosquensis</td><td rowspan="3">Middle upper Carboniferous</td></tr>
<tr><td>$C\tfrac{1}{3}$b</td><td>Cora limestone and oölite with Omph. Whitneyi</td></tr>
<tr><td>$C\tfrac{1}{3}$a</td><td>Limestone with Spir. Marcoui</td></tr>
<tr><td>Middle Carboniferous</td><td>C_2</td><td>Transgression in the Timan</td><td>Moskau bed</td><td>Bed of Spirifer mosquensis</td><td>Lower upper Carboniferous</td></tr>
</table>

Dr. Girty criticizes the statements which I have made concerning certain fossils; but as the invertebrate fauna, exclusive of the insects, is being critically examined by Dr. J. W. Beede who has studied it more thoroughly than anyone else, I will not devote any particular space at present to the consideration of this part of the subject, with the exception of calling attention to some facts which support my identification of the Kansas specimens as *Fusulina.*

Dr. Girty has written as follows:

> It might also be pointed out that just below the Artinsk a zone in the Russian section is characterized by a profusion of *Schwagerina* occurring in association with Fusulinas. Now *Schwagerina* has never been reported from the Mississippi Valley, while I have recently[2] offered reason for believing that the Fusulinas of the Kansas section, if they do not belong to a different genus, at least show important differences from the typical Fusulinas. These facts seem to destroy Mr. Prosser's argument so far as this item of evidence is concerned. At the same time these very forms furnish more stable evidence looking somewhat in the same direction.[3]

[1] *Palaeontographica*, Vol. LV, 1908, p. 149.

[2] *Am. Jour. Sci.*, 4th ser., Vol. XVII, 1904, pp. 234–40.

[3] *Ibid.*, pp. 43, 44.

It is quite true that Dr. Girty wrote me when the manuscript of the Cottonwood Falls folio was being revised, stating "that the common so-called *Fusulina cylindrica*, or *Fusulina secalica*, of the Mississippi Valley is not congeneric with the real *Fusulinas* of Russia, or at any rate belongs to a distinct subgenus."[1] It seemed to me that the specimens in the Cottonwood limestone and associated formations of Kansas were *Fusulina*, which I stated to Dr. Girty. He answered as follows:

> I am sorry that you do not agree with me in the matter of Triticites, but it matters less what you think or what I think than what the consensus of Paleontologic opinion decides. I feel confident Triticites will be accepted as a good subgenus and probably as a genus. Nevertheless I would be glad to convince you and am sending a couple of examples of Fusulina. That from 2,931 shows the fluted partition wall when viewed against its surface. That from 2,957 shows the edges of the partition walls and the pattern which their undulating edges make in conjunction with one another. You doubtless have good specimens of Triticites in your own collection. You will observe that in the latter the partition is quite straight, and if you bear in mind the differences upon which other genera are established among the foraminifera you will feel a little more like accepting Triticites. . . . . Please return the specimens which are from western Texas. They show the same structure as typical Fusulina from Russia, but are much more elongate.[2]

These Texas specimens were compared with some from the Cottonwood limestone of Kansas and specimens of the latter were found with fluted partition walls essentially the same as in the former, according to my observation. I also wrote Dr. J. W. Beede concerning these Kansas specimens, who answered that "the Cottonwood limestone specimens are true *Fusulinas*"[3] and later in answer to my direct question said that "the Cottonwood specimens *certainly* have fluted septa."[4]

The literature also supported the above identification and as far back as 1866 Dr. H. B. Geinitz identified specimens which had been collected by Jules Marcou from Plattsmouth, Nebraska, as *Fusulina cylindrica* Fischer and *F. depressa* Fischer.[5]

In 1872 Meek published the following paragraph under his descrip-

[1] Letter of April 13, 1904.

[2] Letter of May 9, 1904.

[3] Letter of May 11, 1904.

[4] Letter of May 14, 1904.

[5] "Carbonformation und Dyas in Nebraska" (*M. d. K. Leop.-Carol. Akad. d. Naturl.*), p. 71, Pl. V, Figs. 5*a*, *b*, and *c*, and p. 72, Pl. V, Figs. 6*a*, *b*, and *c*.

tion of specimens from the Coal Measures of southeastern Nebraska which he identified as *Fusulina cylindrica* Fischer:

In following the general practice of referring this to the Russian species, I am not only governed by comparisons with figures and descriptions of the latter, but I have had an opportunity to make direct comparison with specimens of *F. cylindrica* kindly sent to me by Colonel Romanowski, of the Russian mining-engineers's department, from the Ural Mountains. It is true these Russian specimens are not in a condition to show very clearly in polished sections the minute details of their internal structure under the microscope, but so far as I have been able to determine from the comparison, they seem to agree well with the American form.[1]

Orestes H. St. John collected specimens from many of the Kansas horizons which he sent to Möller who carefully studied them and referred them to European species. As for example, he referred with a ? mark *Fusulina cylindrica* Meek, Neb. 1872, Report, pp. 140, 141, Pl. 1, Fig. 2, to *Fusulina montipara* Ehren,[2] and in the same way Figs. 3*a* and 3*b*, Pl. V, and Figs. 8*a* and 8*b*, Pl. VII, of the Meek and Hayden report were considered with a ? mark as synonyms of *Fusulina Verneuili* Möller.[3] Later he accepted the species *Fusulina ventricosa* Meek and Hayden for part of the Kansas valley forms; and other specimens, which he stated were very well figured in the Meek and Hayden reports (Pl. II, Fig. 1; Pl. V, Figs. 3*a* and 3*b;* Pl. VII, Figs. 8*a* and 8*b*, and *Palaeontology of the Upper Missouri*, 1865, Pl. I, Figs. 6*a*–6*c*), he considered a variety of the above-mentioned species and denoted it as *F. ventricosa* Meek and Hayden var. *Meeki* Möller.[4] Then follows a list of localities in the Kansas valley from which specimens of these two forms were sent him by Professor Orestes St. John. *Fusulina ventricosa* var. *Meeki* he stated is distributed throughout all the strata from which St. John sent him specimens, and he noted it particularly in those specimens with the numbers 1–5 and 11.[5] This statement is accompanied by a note, apparently furnished by St. John, which states that "No. 11 is in the Kansas valley, bed No. 28, Manhattan, Kan. This is the highest or most recent horizon, in which *Fusulina* has been found and is near the base of the so-called Permo-Carboniferous of American

[1] *Final Rept. U. S. Geol. Surv. Neb. and Adjacent Territories*, p. 140.

[2] *Mém. Acad. Imp. Sci. St. Pétersbourg*, Ser. VII, Vol. XXV, 1878, p. 62.

[3] *Ibid.*, p. 64.

[4] *Ibid.*, Vol. XXVII, 1879, p. 5.

[5] *Ibid.*, p. 6.

geologists. This bed is 330 to 430 feet above No. 95 of the Kansas valley section."[1]

Dr. E. Schellwien has recently stated in his description of *Fusulina montipara* (Ehrbg.) Möller that: those portions of Möller's treatise, which refer to the American forms, are to be stricken out.[2] A footnote on the same page contains the statement by Schellwien that: Möller apparently was in doubt, whether or not the American Fusulinas were identical with *F. montipara.* In the appendix (which the writer has not seen) he has later expressed himself as being opposed to a union of the forms.

Dr. Schellwien has also stated that in America a *Fusulina* occurs in Iowa, Indiana, and Nebraska which is described from there under the name *Fusulina cylindrica* and departs so little from *F. regularis* Schellwien that they probably must be united.[3] The last-named species was reported by Dr. Schellwien from the Upper Carboniferous of the Karnic Alps. In his later work he has again referred to the close relationship existing between the eastern Alpine *Fusulina regularis* and the widely distributed group of North American *F. secalis* [*secalica*] Say.[4]

Dr. Schellwien further said that the so often cited *Fusulina cylindrica* in all probability does not occur in America. The genuine *Fusulina* before me from Iowa, Illinios, Indiana, Missouri, and Nebraska all belong to one and the same group, yet these forms exhibit only a small part of the American Fusulinas.[5] The opinion that *F. cylindrica* Fischer does not occur in the United States is stated more positively in Schellwien's last work on the Fusulinas where he said: The American Fusulinas which will be described in a later number show no relationship whatever to *F. cylindrica.*[6]

Dr. Beede first called attention to the description of the American forms by Say in 1823 under the name of *Miliolites secalicus*, fourteen years earlier than the description of the genus *Fusulina* and European species of *F. cylindrica* by Fischer v. Waldheim, and revived

[1] *Mém. Acad. Imp. Sci. St. Pétersbourg*, Ser. VII, Vol. XXVII, 1879, pp. 5, 6.

[2] *Palaeontographica*, Vol. LV, 1908, p. 185.

[3] *Ibid.*, Vol. XLIV, 1897, p. 251.

[4] *Ibid.*, Vol. LV, 1908, p. 183, n. 4.

[5] *Ibid.*, Vol. XLIV, p. 280, n. 3.

[6] *Ibid.*, Vol. LV, 1908, p. 162, n. 3.

Say's name as *Fusulina secalica* which he used in general for the Kansas specimens which had heretofore been called *F. cylindrica.*[1]

From Hooser, Cowley County, in southern Kansas and probably from the Neva limestone, which occurs some 40 feet below the horizon of the Cottonwood limestone, Erich Spandel described seven genera and nine species of Foraminifera. One of these he identified as *Fusulina* cf. *regularis* Schellwien and stated that the chambers correspond the best with *F. cylindrica* Fischer, modified by Möller, and *F. regularis* Schellwien. Since the outside, however, corresponds to the last species, so I believe, it is identical with the same or quite nearly related.

Those specimens described and figured by H. B. Geinitz from the Permo-Carboniferous of Plattsmouth, Nebraska, under the names of *Fus. cylindrica* Fischer, and *Fus. depressa* Fischer, appear to be identical with those here discussed.

Two of the new species of Foraminifera were named *postcarbonica* and Spandel wrote as follows regarding the correlation of this horizon:

> The genus *Monogenerina* is new which appears to be restricted to the Permo-Carboniferous. The other genera are already known to us from the Carboniferous. The presence of *Fusulina* gives the fauna a more Carboniferous character, the frequent appearance of the Nodosaridæ with three species refers the same, however, to the lower limit of the Permian.[2]

In 1903 Professor J. A. Udden reported "great numbers of *Fusulina cylindrica*" in the calcareous rocks of the Missourian series in Fremont and Mills counties in southwestern Iowa, bordering on Nebraska, which was stated to be interesting "as furnishing an additional item for consideration in correlating the uppermost members of the Carboniferous of America with those of Europe, where the same forms occur at about the same level in the geological scale."[3]

The above observations and statements appeared fairly conclusive; but in order that there might be no mistake a specimen was sent

[1] *Univ. Geol. Surv. Kansas*, Vol. VI, 1900, p. 10.

[2] *Abhand. d. naturhistorischen Gesellschaft in Nürnberg*, 1901, p. 19.

[3] *Jour. Geol.*, Vol. XI, p. 284. For the geological sections and various lists of fossils containing *F. cylindrica* see Professor Udden's report on the geology of these two counties in Vol. XIII, 1903, of the *Iowa Geological Survey*, pp. 137 ff.

over to the late Dr. E. Schellwien at the University of Königsberg, who was generally considered as the leading authority in the world upon the Paleozoic Foraminifera. After examining the specimen he wrote me a letter which has been translated as follows by Berthold A. Eisenlohr, associate professor of the Germanic languages and literatures in the Ohio State University:

BERNSTEINSAMMLUNG DER UNIVERSITÄT 18/7, '04
KÖNIGSBERG I. PR.

MY DEAR COLLEAGUE:

I have examined the Fusulinas, which you were so kind as to send me for investigation, after making thin sections of them. They are genuine Fusulinas of the *Fus. regularis* Schellw. type, a form which is rather widely distributed in America and also occurs in lower horizons as the Cottonwood limestone. I beg to remark that I have at my command a rather large amount of material in North American Fusulinas, most of which comes from the National Museum. *Fusul. cylindrica* does not occur at all in America. I hope to be able to finish my work on the Fusulinas next winter and will then send it to you. I regret that I have not enough separates of my earlier papers in this subject. . . . .

With my kindest regards,

Yours very truly,
(*Signed*) E. SCHELLWIEN

Since the above letter was written H. Yabe, of the Imperial University of Tōkyō, has published "A Contribution to the Genus Fusulina" in which occurs the following statement concerning specimens of *Triticites secalicus* Say sent him by Dr. Girty:

As I examined their sections under the microscope, I was fully convinced of the correctness of his remarks on the peculiar structure of the form; yet I am still in doubt whether it is possible to separate satisfactorily the American form from the group of *Schwagerina* with a fusiform shell, such as *S. fusulinoides* Schellwien and *S. fusiformis* Krotow. The former, according to Schellwien, has "die grosse Centralkammer, die Hin- und Herbiegung der Septen, die in der median Ebene nie den Boden erreichen, Merkmale welche den Fusulinen zukommen," while *Triticites secalicus* possesses, besides these characters, the thick septa of a *Fusulina* s. s. Therefore, until more important differences from *Fusulina* s. s. and *Schwagerina* are found, it seems to me unnecessary to keep *Triticites* as a distinct genus, or even as a new subgenus.[1]

Dr. Schellwien in his last monograph on the Fusulinas under the observations relating to the species *F. montipara* (Ehrbg.) Möller makes the following statement:

[1] *Jour. of the College of Science, Imperial University*, Vol. XXI, Art. 5, 1906, p. 5.

The most important characters of our species consist in the described manner of rolling up, the marked prominence of the mouth, but especially in the slight folding of the septa, a peculiarity which characterizes the majority of American Fusulinas and has led Girty to describe a genus of his own, viz., *Triticites.*[1]

The important point to be noted in all these references to Schellwien's work is that he *always* referred the American forms under discussion to the genus *Fusulina.*

Professors Grabau and Shimer in their excellent work on "North American Index Fossils" list the abundant American species as *Fusulina secalica* (Say) followed by *F. cylindrica* in parentheses as a synonym which is stated to be widely "distributed throughout the Middle and Upper Carbonic."[2] Professor Ernst Koken on his world paleogeographic map of "Land und Meer zur permischen Zeit" shows the genus *Fusulina* in Kansas.[3]

Recently Dr. Beede has found typical Schwagerinas in the Neva limestone associated with *Fusulina* of the *longissima* type on the one hand and with a micro-foraminiferal fauna of Permo-Carboniferous character on the other, similar to that described by Spandel.[4]

It appears, therefore, that the evidence from the Foraminifera is much more strongly in favor of the general correlation which I have made of the Upper Paleozoic rocks of Kansas than I had claimed.

The following statement by Dr. Girty is to be noted: "In a paper just received Mr. Yabe expresses the opinion that the generic term *Triticites,* which I introduced for the type of *Fusulina* found in the Mississippi Valley, is a synonym not of *Fusulina* but of *Schwagerina.*"[5] Then follows nearly a page discussion of the correlation of the Kansas deposits, providing this *change* in generic position of the specimens which he had named *Triticites* be accepted. Dr. Girty

[1] *Palaeontographica,* Vol. LV, 1908, p. 186. Dr. Lewis A. Rhoades, professor of Germanic languages and literatures in the Ohio State University, has looked over this translation together with some others in this article and has kindly suggested some changes which I have made.

[2] *Op. cit.,* I, 1906, p. 12.

[3] *N. Jahrbuch f. Min., Geol., u. Pal.,* Festband 1907, p. 546 and Pl. XIX.

[4] See *Univ. Geol. Surv. Kan.,* Vol. IX, 1909, pp. 348, 374, and Dr. Beede's review of "The Guadalupian Fauna" in *Jour. Geol.,* Vol. XVII, 1909, p. 677.

[5] "The Guadalupian Fauna," *op. cit.,* p. 44.

does not say where this paper by Mr. Yabe may be found; but it appears probable that it is the one cited above. If this be correct then the statements by Mr. Yabe touching this question are as follows: "I am still in doubt whether it is possible to separate satisfactorily the American form [*Triticites*] from the group of *Schwagerina* with a fusiform shell. . . . . Therefore, until more important differences from *Fusulina* s. s. and *Schwagerina* are found, it seems to me unnecessary to keep *Triticites* as a distinct genus or even as a new subgenus."[1] In this paper and preceding ones Dr. Beede and myself have used the generic names of *Fusulina* and *Schwagerina* in the sense in which they are generally used by European and American paleontologists who are particularly acquainted with the Paleozoic Foraminifera; not in the sense here suggested by Dr. Girty.

Dr. Girty cites two other genera, *Pseudomonotis* and *Bakewellia.*[2] The genus *Pseudomonotis does* occur in rocks in Kansas considerably older than those which I have considered Permian; but such occurrence had not been reported when my early papers were published. In regard to *Bakewellia* Dr. Girty says: "After critically examining the best specimens of *Bakewellia* which could be obtained I have been brought to entertain serious doubts as to their generic identity with the Bakewellias of the English Permian as represented in King's monograph. The dentition appears to be different and they seem to lack the characteristic series of ligamentary pits." Dr. Beede who has collected and studied a large number of specimens belonging to this type says that "some of the species probably belong to Yakowlew's genus *Cyrtodontarca* from the Permo-Carboniferous of southeastern Russia, while the others may be closely related to them. The Coal Measures rocks of the world, so far as I am aware, nowhere exhibit the faunal assemblage of these shells and the associated pelecypods found in these strata in Kansas."[3]

The conclusions of Professor Fritz Frech as given in his discussion of the line between the Dyas [Permian] and Carboniferous is of decided interest in this connection and corroborative of the views of Dr. Beede. Dr. Frech wrote as follows, as translated by the late Associate Professor Charles W. Mesloh of the Ohio State University:

[1] *Loc. cit.*, p. 5.

[2] "The Guadalupian Fauna," *op. cit.*, p. 43.

[3] *Jour. Geol.*, Vol. XVII, p. 676.

The dividing line between the Carboniferous and Dyas [Permian] formations cannot be drawn with full certainty in every region since, especially in the Dyas, the development of a local flora is nearly always the rule and decisive differences do not exist in the brachiopod fauna.

Yet an agreement seems to be gradually forming everywhere: The line dividing the Carboniferous from the Rothliegende [lower Permian of Germany] is generally placed between the Ottweiler and Cusel beds; only concerning the determination of the age of the French equivalents of both do differences of opinion still exist.

It is everywhere easy to distinguish Schwagerina strata and the Arta [Artinsk] stage where the Medlicottiadæ and the oldest Arcestidæ occur. If the Arta stage and the Sosio limestone is considered a transitional horizon, i. e., as Permo-Carboniferous, there remains almost nothing of our formation.

Also, where the characteristic Dyas bivalves (*Pleurophorus*, *Schizodus*, *Bakewellia*, *Pseudomonotis*) occur in masses (Kansas) there can be no doubt about the dividing line. The great development of the Stegocephala, whose Carboniferous ancestors occur sparingly, is also characteristic of the Dyas.

On the other hand, the development of the still very widely distributed brachiopods is such, that only in the lower Dyas of the Mediterranean district a few new genera, and in the north only a few new species appear. To offset the slow retrogression of the Carboniferous brachiopod group, as we see e. g. in Kansas, there are no additions of any kind.[1]

Professor Frech's deduction from the evidence of the Kansas pelecypods is quite different from that of Dr. Girty and is important to bear in mind in considering the age of these formations. Dr. Frech wrote that: in the brachiopod formations enter layers agreeing petrographically which contain a fauna of small Dyas bivalves (*Bakewellia*, *Pleurophorus*, *Schizodus*). But in the two transition horizons (Neosho and Chase) the Carboniferous brachiopods predominate. The Marion strata are the first to be filled exclusively by upper Dyas bivalves and with variegated gypsum-bearing marls devoid of fossils.[2]

Dr. Girty states that "he [Prosser] finds the Kansas 'Permian' fauna much more distinct from the underlying Pennsylvanian than appears to me warranted, and he correlates it too confidently with the Russian Permian."[3] In regard to the opinion expressed in the first clause of the above sentence those who have followed this discussion have seen that there are other paleontologists who have

[1] *Lethaea geognostica*, "Lethaea paleozoica," 2. Band, 3. Lief., 1901, pp. 490, 491.

[2] *Ibid.*, 2. Lief., 1899, p. 377.

[3] *Op. cit.*, p. 42.

studied the fossils of these deposits who find the differences between the Kansan Pennsylvanian and Permian life greater and more marked than I have ever claimed. As to the second opinion I have attempted to consider *all* evidence concerning the age of these formations, whether it agreed with the results of my studies or not, and to give it due weight in forming my opinion regarding the correlation of these deposits.

Concerning the correlation of the Kansas deposits with the Russian Permian it is interesting to note that Murchison—the author of the Permian system—accepted it. He wrote as follows:

> Only of late years have we obtained information of the Permian species of America. It is interesting to find there that the same genera characterize the last of the Palaeozoic systems as in Europe. In Kansas, Texas, and Nebraska, Permian rocks occur containing Productus, Camarophoria, Strophalosia, Streptorhynchus, Chonetes, Spirifer, Edmondia, Gervillia, Monotis, Schizodus, Murchisonia, Orthoceras, Bellerophon, and Fenestella. Not only are the genera the same there as in the eastern hemisphere, but in several cases the species are identical with those found in the Magnesian Limestone and Zechstein. These fossils have been described by Messrs. Meek and Hayden, Swallow and Hawn, Shumard, and very recently by Geinitz.[1]

Since the writer's last reviews of the literature regarding the correlation of the Upper Paleozoic of Kansas and related regions[2] several papers have been published which are of importance in this discussion. In this last review, however, I seem to have overlooked Dr. C. R. Eastman's paper on the "Carboniferous Fishes from the Central Western States" in which he reviewed briefly the correlation of the Upper Paleozoic formations of the Kansas-Nebraskan area and wrote as follows:

> But in the upper terrane, the so-called "Red Beds" or Cimarron series, which exhibit a thickness further southward of from 1,000 to perhaps 2,200 feet, no fossils have been found which are at all closely related to those of the Coal Measures, and writers are pretty generally agreed in correlating this series with the Upper Permian (Neo-Dyas) of Europe.
>
> In the same way there appears to be good reason for believing that the lower part of the Big Blue series (Chase and Neosho strata) correspond to the Artinsk stage, which is the oldest Permian of Russia.[3]

[1] *Siluria*, 5th ed., 1872, pp. 341, 342.

[2] *Jour. Geol.*, Vol. X, 1902, pp. 721–37; *Amer. Geologist*, Vol. XXXVI, 1905, pp. 142–62.

[3] *Bull. Mus. Comp. Zoölogy Harvard College*, Vol. XXXIX, 1903, p. 165.

I will now mention several articles which are somewhat remotely related to the Kansas question. A collection was made in 1901 from the Wichita beds near Seymour, Baylor County, in northern Texas for the Royal Museum of Munich by Charles H. Sternberg who had previously collected in the same general region for the Museum of Comparative Zoölogy of Harvard University and for Professor Cope, a popular account of which may be found in his book.[1] The specimens sent to the Royal Museum of Munich have been described by Dr. Ferdinand Broili and L. Neumayer and it is to be especially noted that Dr. Broili made a trip to this country and spent two weeks in the field with Mr. Sternberg while the collection was being made. Dr. Broili in his monograph describing the Permian Stegocephals and reptiles of Texas in this collection has expressed the following opinion concerning the age of the deposits in Vermilion County, Illinois, which Professor Cope called Permian, and those near Seymour in northern Texas under his general discussion of the Permian of Illinois and Texas: The Wichita beds in Texas compared with the bone bed of Illinois in my opinion represent in point of time the younger formation.[2] Near the close of this discussion Dr. Broili again referred to the correlation of the Permian deposits of these two states as follows: These circumstances, I believe, make the supposition appear legitimate that the strata of Texas, when compared with exposures in Illinois, represent in point of time the younger formation. Another point which likewise favors this opinion is the fact that the genera from the two localities agree, but not the species.[3]

Finally, near the close of the monograph, under his general conclusions, Dr. Broili made the following statement concerning the vertebrate fossils: As we may then infer from the foregoing, the vertebrate fossils from the North American Permian consequently afford a considerable number of points of similarity with European and African forms; these relations might turn out to be even closer, especially if the Russian deposits should be more carefully investigated in their paleontological relations.[4]

[1] *The Life of a Fossil Hunter*, 1909, pp. 205–65.

[2] *Palaeontographica*, Vol. LI, 1904, p. 5. This monograph, however, did not come under my notice until after the publication of my paper of September, 1905.

[3] *Ibid.*, p. 6.

[4] *Ibid.*, p. 105.

Broili's monograph is followed by L. Neumayer's paper on the coprolites of the Texas Permian, which form a part of the above-mentioned collections.[1]

Professor Case has spent considerable time in studying the stratigraphy and fauna of the Red Beds of northern central Texas and has published several papers relating to the subject. One is entitled "The Character of the Wichita and Clear Fork Divisions of the Permian Red Beds of Texas."[2] The last one is called "A Great Permian Delta and Its Vertebrate Life, with Restorations by the Author."[3] A slightly earlier one is "On the Value of the Evidence Furnished by Vertebrate Fossils of the Age of Certain So-called Permian Beds of America."[4] In this paper the vertebrate evidence concerning the age of certain beds in Illinois and Texas is considered and the author's conclusions are as follows:

> 1. The evidence from vertebrates is not sufficient to demonstrate the Permian age of the beds in Illinois and Texas, they may reach down into the Carboniferous or they may extend upward into the Triassic.
>
> 2. There is no unlikelihood that reptilian life began in the Carboniferous. The evidence is rather affirmative than otherwise.
>
> It is becoming more and more evident from the vertebrate paleontology that the Red Beds of North America and their eastern equivalents represent an enormous interval of emergence which may well have begun while Carboniferous (Pennsylvanian) forms still lingered in the waters and have continued until Triassic types were well established.[5]

The last paper dealing with the stratigraphy of this part of Texas was read by Professor C. H. Gordon at the Baltimore meeting and was entitled "The Red Beds of the Wichita-Brazoo Region of North Texas." He stated that—

> formations to which the names Wichita and Clear Fork have been given, when traced along their strike toward the southwest, are found to grade into those included under the terms Cisco and Albany. The former have been regarded as Permian, while the latter have usually been assigned to the Pennsylvanian. Some authors, however, have suggested that the Albany should be considered Permo-

[1] *Palaeontographica*, Vol. LI, 1904, pp. 121–28, Pl. XIV.

[2] *Am. Mus. Nat. Hist.*, Vol. XXIII, 1907, p. 659.

[3] *Pop. Sci. Month.*, Dec. 1908, p. 557.

[4] *Jour. Geol.*, Vol. XVI, Sept.-Oct., 1908, p. 572.

[5] *Ibid.*, p. 580.

Carboniferous. . . . . It is the conclusion of the author that the Red Beds of this region are the near-shore representatives of the Albany and the decision as to their age will rest upon that of the latter.[1]

The above paper in part appears to support the earlier conclusions of Professor W. F. Cummins who had "found the fact well established that the Wichita and the Albany divisions were the same in time of deposition."[2] This opinion was positively and clearly stated in 1908 by Professor Cummins in his paper on "The Localities and Horizons of Permian Vertebrate Fossils in Texas" where he wrote as follows:

These beds in the southern part of this field were called the Albany beds and were assigned to the Coal Measures. Subsequent study, however, disclosed the fact that the beds were stratigraphically continuous with the Wichita, being simply deposits in deeper waters, and in all subsequent publications they have been included in the Wichita, referred to the Permian, and the name Albany dropped.[3]

Dr. Percy E. Raymond has discovered reptilian and amphibian fossils near Pitcairn, fifteen miles east of Pittsburgh, Pennsylvania, in the upper part of the Pittsburgh red shale which occurs near the middle of the Conemaugh formation of the Pennsylvanian series.[4] These fossils have been described by Professor Case who states that "in general the collection resembles rather those from Texas than those from Illinois, but the specimens are far too few to base any generalizations as to distribution upon them."[5] His conclusion is that—

it certainly places the advent of a distinctly terrestrial reptilian fauna earlier than has hitherto been supposed. The suggestion may not be impossible that conditions for terrestrial life of a high order were reached earlier in the east than in the west, and that the Carboniferous swamps of Pennsylvanian time, giving place to upland surfaces before the advance of the Appalachian uplift, made possible a type of life that was homotaxially equivalent to a similar type, which developed at a later time in the west.[6]

Dr. I. C. White regards this discovery by Dr. Raymond as strongly confirmatory of the Permo-Carboniferous age of the main portion of

[1] *Science*, N. S., Vol. XXIX, May 7, 1909, p. 752.

[2] *Trans. Texas Acad. Sci.*, Vol. II, 1897, p. 97.

[3] *Jour. Geol.*, Vol. XVI, pp. 738, 739.

[4] *Science*, N. S., Vol. XXVI, Dec. 13, 1907, p. 835.

[5] *Annals Carnegie Mus.*, Vol. IV, 1908, p. 235.

[6] *Ibid.*, p. 240.

the Conemaugh, which he had suggested at an earlier date,[1] and writes as follows concerning it: "The possibility that the lowest *Conemaugh reds* might mark the dividing line between important formations, such as the true *Coal Measures* and the *Permo-Carboniferous*, has received strong confirmation during the past year."[2] In the chapter on the "Monongahela Series" Dr. I. C. White states that "hence there can be little doubt that this upper two-thirds of the *Conemaugh series*, together with the deposits of the *Monongahela*, correlate in time with the *Permo-Carboniferous* beds of Europe."[3]

Mr. Ralph W. Stone has published the following opinion concerning the age of the Dunkard formation, which is the one succeeding the Monongahela:

> The organic remains of the Dunkard group, according to David White, comprise fossil plants in large numbers and ostracods with occasional occurrences of pelecypods and fish fragments. . . . .
>
> This flora of the Dunkard is interesting on account of species that are either unique or closely related to forms present in rocks of Mesozoic age.[4]

Dr. G. C. Martin has recently made the following statement concerning the same question: "The equivalents of these beds [Dunkard] in Pennsylvania and West Virginia have, from a study of their floras and faunas, been referred to the Permian series of the Carboniferous. Some doubt still exists as to their age, but in all probability they are, in part at least, Permian."[5]

In the "Tableau du Synchronisme des Assises Permiennes" in the last edition of De Lapparent's *Traité de géologie* the Permian is subdivided into three *étages* which in ascending order are the Artinskian or Autunien, Penjabien or Saxonien, and Thuringien. The Kansan formations are correlated as follows in this table: the Neosho and Chase are put in the Artinskian or Lower Permian; the Marion and Wellington in the Penjabien or Middle Permian; and the Red Beds or Cimarron series in the Thuringien or Upper Permian.[6] Under the discussion of the Penjabien or Middle Permian

[1] *W. Va. Geol. Surv.*, Vol. II, 1903, p. 256.

[2] *Ibid.*, Vol. Two (A), 1908, p. 622. [3] *Ibid.*, p. 687.

[4] *Geologic Atlas U. S.*, Folio No. 121, 1905, p. 7.

[5] *Ibid.*, Folio No. 160, 1908, p. 8.

[6] *Op. cit.*, 5th ed., 1906, p. 1026.

is the statement that "Les *Marion beds* du Kansas, à *Bakewellia* et *Pseudomontis*, sont peut-être de cet âge, ainsi que les *schistes de* Wellington."[1] Under that of the Thuringien it is stated that "Les couches de *Cimarron*, qui font partie des *red beds* et surmontent l'assise de Wellington, renferment dans l'Oklahoma des lits à *Pleurophorus* et *Bakewellia*. Il s'y trouve du gypse et des dolomies."[2]

On the "Carte Géologique de l'Amérique du Nord," compiled by Bailey Willis and published in 1906 for distribution at the tenth session of the International Geological Congress in September of that year in Mexico, the area of the rocks under discussion extending from southeastern Nebraska southwesterly across Kansas and Oklahoma to central Texas is mapped as Permian. Professor Willis made the following statement concerning it:

> Les couches de la période Carbonifère sont parmi les plus differentiées de l'Amérique du Nord; on y reconnaît ordinairement trois divisions principales: le Mississippien, le Pennsylvanien et le Permien, et ces divisions sont représentées sur la carte autant qu'elles peuvent être distinguées. . . . . Le Permien (Formation Dunkard) de la Pennsylvanie n'est pas représenté séparément. Le Permien du Nouveau Brunswick est montré sur la carte ainsi que la large zone de grès permiens et de couches rouges qui s'étend vers le sud-ouest, depuis le Kansas jusqu'au Texas.[3]

Professors Chamberlin and Salisbury fully accept the Permian age of the Kansas deposits as is shown by the following excerpts from their magnificent work on general geology:

> West of the Mississippi, the Permian system has a more extensive development [than to the east], though far less widespread than the Pennsylvanian. The Permian strata are best known in Texas, Kansas, and Nebraska, and though the sea was not entirely excluded from this region, it appears, where present, to have been shallow. Locally and temporarily, inland seas were cut off from the ocean. Early in the period the Texan area of sedimentation seems to have been separated from the Kansan by the beginnings of the Ouachita mountains. . . . .
>
> In Kansas and Nebraska the older Permian beds are marine. . . . . The marine Permian of Kansas is overlain by beds containing gypsum and salt and possessing other features which show that the open sea of the region was succeeded by dissevered remnants, or by salt lakes whose supply of fresh water was exceeded

[1] *Ibid.*, p. 1016.

[2] *Ibid.*, p. 1025.

[3] *Congrès Géologique International*, Compte Rendu, Xème Session, Mexico, 1906, 1st fas., 1907, p. 219.

by surface evaporation. Connected with these saline and gypsiferous deposits, and overlying them, are the "Red Beds," sometimes referred to the succeeding Trias; but they appear to be late Permian, in the main at least.[1]

Professor Scott also states a similar conclusion in his general work on geology where he says that:

In the region beyond the Mississippi the Permian beds thicken southward, attaining in southern Kansas a thickness of 2,000 feet, and in Texas of more than 5,000 feet. The mountains of Oklahoma, which may have been raised late in the Carboniferous or early in the Permian, separate the Texas and Kansas areas. . . . .

In the latter part of the period, lagoons were cut off from the sea and converted into salt and bitter lakes in which the salt and gypsum of Kansas and the gypsum of Oklahoma and Texas were precipitated. Occasionally the sea broke into these lakes, bringing a marine fauna with it for a short time.[2]

Professor Scott is an accomplished vertebrate paleontologist and under his account of "Permian Life" is the statement that—

the most important character that distinguishes the life of the Permian from that of all preceding periods is the appearance in large numbers of true *Reptiles*. There is no reason to suppose that such a variegated reptilian fauna can have come into existence suddenly, and their ancestors will doubtless be discovered in the Carboniferous; but while no true reptiles are certainly known from the latter, in the Permian they are the most conspicuous elements of vertebrate life.[3]

Under the description of the Carboniferous Dr. Kayser, the distinguished professor of geology in the University of Marburg, writes that: The marine Upper Carboniferous of Kansas has become known to us in particular through the numerous works of Charles Prosser. Tschernyschew and others have brought out most prominently the great similarity of the fauna with that of the Timans and Urals.[4]

Finally, under the description of the Permian Dr. Kayser states:

In the United States we find in the east (Virginia, Pennsylvania, and so forth) conformably over the productive upper Carboniferous [Upper Productive Coal Measures] the so-called Barren Measures [Upper Barren]. They contain *Callip-*

[1] *Geology*, Vol. II, 1906, pp. 620, 621; also, see *A College Text-Book of Geology*, by the same authors, 1909, pp. 660, 661.

[2] *An Introduction to Geology*, 2d ed., 1908, p. 639.

[3] *Ibid.*, p. 652.

[4] *Lehrbuch d. Geologie*, 3d ed., Pt. II, "Geologische Formationskunde," 1908, p. 236.

teris conferta, *Taeniopteris*, and other characteristic Permian forms together with Carboniferous types of plants exposing, probably, a representation of our Rothliegende.

In the western and southern states, on the other hand, there occurs quite similar to that in Russia, closely associated with extensive marine upper Carboniferous deposits, in large part chalky, equally extensive marine Permian deposits, likewise largely chalky. This is especially so in Kansas, Nebraska, and the adjoining territory. The beds in question, designated by very different names (Wichita and Clear Fork beds [Cummins], Neosho, Chase and Marion [Prosser], etc.), contain in the lower part numerous Theriodonts (*Naosaurus* and others), Stegocephals (*Eryops*, *Cricotus*), and fish (*Pleuracanthus*, *Janassa*, etc.), recognized by Cope as Permian; in the upper part, beside numerous mostly Carboniferous species (especially Brachiopods—*Productus*, *Marginifera*, *Enteles*, *Derbyia*, *Camarophoria*, *Spirifer*, etc.—, Lamellibranchs and Gastropods), are Permian Ammonites (*Medlicottia*, *Popanoceras*, *Waagenoceras*). Above follows, as representative of the upper Permian, a predominant red-colored, unfossiliferous formation composed of sandstones, clays, and shales, gypsum and salt bearing, comparable to the Russian Tartarian group.[1]

The Tartarian is the upper stage of the Russian Permian and some of the Russian geologists have considered it as of Triassic age.

Dr. E. H. Sellards has described under the title of "Types of Permian Insects"[2] a rich insect fauna found in the Wellington shales, three and one-half miles southeast of Banner City, Dickinson County, Kansas. Over two thousand specimens have been collected and it is stated to be "the most complete record of Permian insect life thus far obtained."[3] The last paper contains a section on the "Correlation of the Insect-bearing Horizon" in which the most striking characters of the fauna are pointed out. It is stated:

The order Plecoptera, or Ephemerids, is somewhat abundant in the Wellington shales. In Part II of this paper I have described ten genera and thirteen species constituting a new family of this order. Insects which appear to be prototypes of the Ephemerids exist in some abundance in the Coal Measures. Handlirsch has recognized Ephemerids as occurring sparingly in the Permian of Russia. With this exception true Ephemerids have not previously been identified from Paleozoic deposits. The relative abundance of this group of insects in the Wellington shales affords an exceptionally strong argument for the Permian age of that formation.[4] . . . .

[1] *Ibid.*, pp. 301, 302.

[2] *Am. Jour. Sci.*, 4th ser., Vol. XXII, 1906, p. 249; *ibid.*, Vol. XXIII, 1907, p. 345; and *ibid.*, Vol. XXVII, 1909, p. 151.

[3] *Ibid*, 4th ser., Vol. XXII, p. 249.

[4] *Ibid.*, Vol. XXVII, Feb., 1909, p. 170.

It has usually been observed in collecting from Paleozoic localities, that cockroaches exceed in number of individuals all other insects combined. In the Wellington shales the cockroaches are much in the minority. A collection of something over two thousand insect specimens was found to contain only about seventy cockroaches. From these, two genera and ten species were identified. Of the two genera, one is the well-known Coal Measure and Permian genus *Etoblattina*. The second genus is new. The ten species obtained are new. The rarity of cockroaches in the Wellington is in marked contrast to their relative abundance in most Coal Measure and early Permian localities.[1] . . . .

Among the few insects obtained from the Permian formation of Russia, Handlirsch recognizes, as previously stated, the occurrence of true Ephemerids. The Russian deposits have also yielded forms regarded as representing Paleo-hemiptera and Mantoidæ. These last two groups have not been recognized in the Kansas Permian. The presence of the Ephemerids, however, forms a strong tie in common between the insects of the Russian and the Kansas Permian.[2]

Fossil plants which are associated with the insects at this locality have also been described by Dr. Sellards, and he writes in no uncertain way concerning their geological age. He says:

In the writer's opinion, the plant fossils indicate unequivocally the Permian age of the formation from which they come. The evidence as to the age of the Wellington shales, derived from the flora, is thus summarized in the report referred to [*Kansas University Geological Survey*]: "More than two-thirds of the Wellington species are either identical with or most closely related to species or genera characteristic of the European Permian. The points which seem to have the most importance as bearing on correlation of the Wellington are the following: (1) The complete absence from the Wellington of species in any way confined to or distinctive of the Coal Measures. (2) The comparatively small number of species originating as early as Upper Coal Measure time. (3) The presence of a few species common to and characteristic of the Permian of Europe. (4) The close relation of the new forms to species characteristic of the European Permian. (5) The distinctly Permian facies of the flora as a whole and its marked advance over the flora of the Upper Coal Measures.

"The advance in the flora consists in the number of species and in the abundance of individuals of callipterid and tæniopterid ferns, and of the new fern genus, *Glenopteris*, which appears to be related, on the one hand, to callipterid ferns of Permian types, and, on the other, to the Triassic genera *Cycadopteris* and *Lomatopteris*.

"The evidence derived from the fossil plants as a whole seems to assure the reference of the Wellington to the true Permian in the European sense."

[1] *Am. Jour. Sci.*, 4th ser., Vol. XXVII, Feb., 1909, p. 171.

[2] *Ibid.*, pp. 172, 173.

This conclusion drawn from the plant fossils is now fully confirmed by the evidence derived from the insects.[1]

Dr. Sellards also describes a flora from the Wreford limestone concerning which he writes as follows:

A good deal of interest is attached to the discovery of plants in the Wreford limestone, especially as this formation has been recently regarded as the base of the Permian in Kansas. Nine species have been obtained from this locality as follows: *Baiera* sp., *Callipteris conferta*, *Callipteris* sp., *Cardiocarpon* sp., *Carpolithes* sp., *Cordaites* sp., *Rhabdocarpus* sp., *Sigillaria* sp., *Walchia pinniformis*. The collection obtained from this formation is small and comes from a single locality near Reece, Kan. The association of the flora so far as obtained is with Wellington rather than with Coal Measures flora. The presence of *Walchia* in abundance, and of callipterid ferns, along with the small species of seeds common to the Wellington, together with the absence, so far as yet noted, of all of the common Coal Measures species, gives the flora of the Wreford, as developed at Reece, a distinctive Permian facies.

Coal Measures species, although rare in the collection obtained from the Wreford limestone at the Reece locality, recur in some abundance in the horizon at Washington, regarded by Beede as near the top of the Chase formation.[2]

At the Baltimore meeting, December 31, 1908, Dr. Beede presented a most important paper on the "Relationships of the Pennsylvanian and Permian Faunas of Kansas and Their Correlation with Similar Faunas of the Urals." He stated that "owing to physical changes which occurred during the close of Pennsylvanian time, there occurred a great reduction of Pennsylvanian species, followed by the introduction of Permian species. This introduction of new species becomes very noticeable in the Elmdale formation and its base is considered the base of the Kansas Permian."[3]

Since the above was written the writer has received the May-June number of the *Journal of Geology* in which appears the correlation paper on the "Upper Carboniferous" by George H. Girty[4] followed by the one on "The Upper Paleozoic Floras, Their Succession and Range," by David White,[5] both of which were read at the Baltimore

[1] *Op. cit.*, p. 173. Also see *Univ. Geol. Surv. Kansas*, Vol. IX, 1908 [1909], p. 463.

[2] *Ibid.*, Vol. IX, pp. 463, 464.

[3] *Science*, N. S., Vol. XXIX, April 16, 1909, p. 637. Also see *ibid.*, May 7, 1909, p. 752.

[4] *Op. cit.*, Vol. XVII, July, 1909, pp. 305–20. [5] *Ibid.*, pp. 320–42.

meeting of the American Association for the Advancement of Science, in December, 1908. It is too late to discuss or make use of these papers in this article. It may be said, however, that Dr. Girty states that "the propriety of employing the term Permian in the geology of North America seems to me decidedly doubtful, at least in so far as the evidence of invertebrate fossils is concerned."[1] Mr. White, on the other hand, discusses, under "the Permian floras," following the account of "the Carboniferous floras," those from the Permian of Prince Edward Island, the Dunkard of southwestern Pennsylvania and West Virginia, the Chase of Kansas, and the Wichita of Texas, all of which he apparently places in the Permian. These will be followed immediately by another correlation paper on "The Faunal Relations of the Early Vertebrates" by Professor Samuel W. Williston.[2] Later will appear a critical review of "The Guadalupian Fauna,"[3] and a correlation article on "The Bearing of the Stratigraphic History and Invertebrate Fossils on the Age of the Anthracolithic Rocks of Kansas and Oklahoma,"[4] both of which are by Dr. J. W. Beede. Finally, it may be said that Dr. Beede has studied the stratigraphy, distribution, and invertebrate paleontology of the Upper Paleozoic or Anthracolithic deposits from Nebraska to Texas more thoroughly than any other geologist has yet done and, therefore, his conclusions are entitled to most careful consideration.

July 24, 1909

While this article is passing through the press certain additional information has reached me. The following letter from Professor Yakowlew is important since it gives a summary of the present opinion of the Russian geologists concerning the classification of the Artinsk:

Institute of Mines, St. Petersburg
November 30, 1909

Professor Ch. S. Prosser, Ohio State University, Columbus, Ohio:

Dear Sir: You ask me some questions concerning the Upper Paleozoic deposits of Russia. You wish to know where I draw the line between the Carboniferous and Permian systems in Russia and in which system I place the Artinsk.

[1] *Jour. Geol.*, Vol. XVII, July, 1909, p. 319.

[2] *Ibid.*, pp. 389–402.

[3] *Ibid.*, pp. 672–79.

[4] *Ibid.*, pp. 710–29.

The question about the Artinsk can be solved by comparing its fauna with the fauna of the Permian lying higher and that of the upper Carboniferous lying lower. I think there would be more resemblance with the fauna of the upper Carboniferous. However, the thickness of the Artinsk and the Permian is not very great and their fauna may not be very different. On the other hand some Russian authors are inclined to relate Artinsk to the Permian system; they do so on historical foundation, as the extent of the Carboniferous system had been determined in science before Murchison and we have no right to enlarge it by adding Artinsk. We may sooner unite Artinsk with the Permian system, the extent of which is not so definitely established as that of the Carboniferous. In Russia the term Permocarboniferous is used to designate Artinsk, if it is not related to the Permian nor to the Carboniferous systems, but placed between them, as done by Karpinsky (though without sufficient paleontological grounds), when he established Artinsk. If Artinsk is united with Carboniferous system, the term Permocarboniferous will not have to be used in the sense just mentioned, it will be superfluous. No one in Russia is inclined to designate by the name Permocarboniferous the total of the Permian and the Carboniferous systems, as it is sometimes done in the West of Europe. The Russians keep to one of the two opinions, they either take Artinsk for the Permocarboniferous, that is for the intermediate between the Carboniferous and the Permian, or unite it with the Permian. But I do not think anyone would unite it with the Carboniferous. I think that there might be Artinsk in Kansas and in Nebraska, as there is much in common between the Donetz fauna described by me, with the fauna of Kansas and Nebraska. But whether the Permian fauna exists in North America is an open question to me. . . . .

Yours sincerely,

NICHOLAS YAKOWLEW

Dr. Fritz Frech, the distinguished professor of geology in the University of Breslau, has written me as follows under date of December 21, 1909:

Answering your kind letter of the end of October I give my opinion on the Dyas [Permian] as follows: I include the Arta [Artinsk] stage in the lower Dyas as the type of this lower stage. I have had no ground to change the opinions, expressed in *Lethaea palaeozoica* (2. Band, commencing on p. 493), concerning the correlation of the Dyas.

A letter from Alexander Krasnopolsky, Géologue en chef du Comité géologique de Russie, was received January 6, 1910, a translation of which follows:

The Permo-Carboniferous deposits of the western slope of the Urals—investigated by me—represent two formations, the Artinsk and the Kungur.

These deposits are characterized (aside from the species particularly peculiar to them) by Carboniferous and also by Permian species.

Since these deposits lie directly over the Fusulina limestone of the Urals (which must be looked on as equivalent to the very uppermost formations of the Carboniferous), we may not refer the deposits in question to the Carboniferous system.

On the other hand, I do not find it wholly easy to refer these deposits (and the Lower and Middle Productus limestone of India corresponding to them) to the Permian formation, as I earlier thought possible; for the Permian system, in the sense used by Murchison, itself must begin only with the formations which lie over the Kungur strata—more exactly, only with the limestones of the Province of Kostroma, which contain an older fauna than does the Zechstein of western Europe.

It is interesting to note that what Dr. Tschernyschew said of the outcrops of Artinsk and Upper Carboniferous near the city of Oufa in eastern Russia is certainly paleontologically suggestive of the Kansan deposits. He wrote as follows:

Les bords pittoresques du lac de l'usine de Simsk offrent une coupe classique pour l'étude des dépôts d'Artinsk et des sédiments carbonifères sousjacents. . . . .

Les calcaires qui alternent avec les grès consistent par places presque en entier en grosses fusulines (*Fusulina Verneuili* Moell.). Près de la même digue on voit apparaître de dessous les grès d'Artinsk et en concordance avec lui le grès carbonifère qui contient, avec coquilles de *Fusulina Verneuili* Moell., *Productus semireticulatus* Mart., *Productus longispinus* Sow., *Martinia glabra* Mart., des restes de *Dielasma* et de *Spirifer* (du type de *Spirifer mosquensis* Fisch.).[1]

The argument has been advanced that because Carboniferous brachiopods occur in the Kansas deposits, which I have referred to the Permian, they could not belong in the Permian system. Professor Diener has studied exhaustively the faunas of the Salt Range Productus limestone of India and the Alpine Permian and in a recent letter he refers to the results of this study. If his conclusions are correct it will be seen that the occurrence of Carboniferous brachiopods in deposits superjacent to those which contain Foraminifera characteristic of the uppermost Carboniferous of Russia, as is the case in Kansas, is no argument at all against the Permian age of these Kansan deposits. Professor Diener calls attention to the dis-

[1] *Guide des Excursions du VII Congrès Géologique International,* III (A partir de la ville d'Oufa jusqu'au versant oriental de l'Oural), 1897, pp. 21, 23.

pute as to the Carboniferous or Permian age of the Salt Range Productus limestone and then says:

> This erroneous correlation [with the Upper Carboniferous] is based on the exaggerated importance of numerous species of Brachiopoda which are common to both rock-groups [Carboniferous and Permian]. . . . . I have examined large collections of Himalayan anthracolithic fossils, the descriptions of which have not yet been published, and I am convinced now of the absolute impossibility of basing any safe correlation on the evidence of brachiopods. I have found that the majority of brachiopods considered hitherto as typical leading fossils of Permian beds are distributed equally through Carboniferous and Permian rocks. Foraminifera are far more important as stratigraphical evidence. The fusulinae of the Productus limestone of the Punjab differ specifically from those of the Russian Upper-Carboniferous rocks. So do the Ammonites, whereas the brachiopod fauna undergoes but very little change between the two systems.
>
> I have recently prepared a paper on the brachiopod fauna of the Alpine Bellerophonkalk. This is a stage, which from its stratigraphical position must be placed rather high in the Permian system. In its brachiopod fauna truly Carboniferous types, however, still predominate, thus proving the insufficiency of brachiopods for exact correlations.[1]

Mr. G. B. Richardson, Dr. J. W. Beede, and Mr. David White presented papers, based on their field work of last summer, at the Boston-Cambridge meeting of the Geological Society of America which prove the Permian age of the Kansas deposits which I have referred to that system. The following abstract of Dr. Beede's article on "The Correlation of the Guadalupian and Kansas Sections" was published in the "Preliminary List of Papers" for that meeting:

> The Guadalupian limestones of western Texas and southern New Mexico are overlain by the Pecos Valley Redbeds. These beds present the same lithologic features and are of similar succession as the Redbeds on the eastern side of the Llano Estacado and carry a fauna closely related to them. The gypsums appear to be the equivalents of the Greer gypsums as exposed in Oklahoma and Texas. If this correlation is correct, then the base of the Capitan limestone is on the same stratigraphic level, approximately, as the base of the Elmdale formation of Kansas and the base of the Guadalupian series on the level of the base of the Cherokee shales. The five thousand feet of Hueco beds would fall below this level.

The same list also contained the following abstract of Mr. White's paper on "Permian Floras in the Western 'Red Beds'":

[1] Letter of November 24, 1909.

Characteristic floras, found in a brief tentative search of red beds at three points in Colorado and New Mexico, not only prove Permian age but also indicate great thickness of Dyas in certain "Red Beds" sections in the Rocky Mountains. Examination of lower middle Wichita in Texas and additional collections from Chase (Wreford and Winfield beds) and Wellington of Kansas and from Red Beds within the same limits in Oklahoma confirm lower Permian correlations.[1]

A recent article by Dr. Austin F. Rogers of Stanford University is important in noting the similar mineral deposits in the upper part of the Big Blue series (Lower Permian) of Kansas and those of the Zechstein (Upper Permian) of Germany, and calling attention to the probable arid climate in the northern hemisphere during Permian time which these mineral deposits indicate also prevailed during that time in Kansas. Dr. Rogers writes as follows:

The salt and anhydrite occur in the lower Permian. According to Plate V of the report on Kansas salt,[2] the salt-beds are between the Wellington and Marion formations. Not a single fossil was found on the saltmine dumps, and this is not strange when we consider the conditions under which these deposits were formed. From evidence gathered in various places it seems certain that throughout the northern hemisphere an arid climate prevailed in the Permian. The poverty of fossils, the occurrence of Red-beds, and the presence of extensive beds of gypsum and salt, all point to the fact that Kansas was like the rest of the northern hemisphere during Permian time. Now the occurrence of anhydrite with the salt is additional evidence that the Kansas Permian is like the Permian (Zechstein) of Germany during which time the salt deposits of Stassfurt, Leopoldshall, Vienenburg, and Bernburg were formed. At all these localities anhydrite occurs with salt.[3]

The following recent letter from Professor P. Krotow of the University of Kasan, Russia, who has thoroughly studied the Artinsk and associated formations of Russia, is especially important in giving a brief general account of these formations together with a table showing their correlation with the corresponding ones of western Europe. The letter was written in English in which only two or three minor changes have been made:

The term Permo-Carbon is used in Europe with two meanings: (1) The French call the Permo-Carboniferous system the united deposits of both systems:

[1] Twenty-second winter meeting, Boston-Cambridge, Mass., December 28–30, 1909, p. 24.

[2] *Annual Bulletin of the Mineral Resources for 1908.*

[3] *Am. Jour. Sci.*, 4th ser., Vol. XXIX, March, 1910, p. 260.

the Carboniferous and the Permian; (2) In Russia we call Permo-Carbon the intermediary horizons between the Carboniferous and the Permian systems, characterized by a mixed fauna and flora, consisting of Carboniferous and Permian species with the incorporation of some original species, which are met with only in these layers.

In Russia,[1] as well as in western Europe, these intermediary horizons are composed of layers previously looked upon partly as Carboniferous, partly as Permian.

For instance, in Russia in the composition of Permo-Carbon enter: The Artinsk or pepper sandstone, which Murchison referred to the Carboniferous system, as well as the limestone and plaster-stone of Kungur, which Murchison referred to the Permian. Artinsk or pepper sandstone with Permo-Carboniferous fauna composes the Artinsk-Stufe, the lower layers of Permo-Carbon. It lies immediately on several kinds of limestone (Fusulina limestone and Schwagerina limestone), which must be unconditionally related to the Carboniferous system. On "Artinsk-Stufe" lies the "Kungur-Stufe" which forms the upper layers of Russian Permo-Carbon. On these strata in Russia lie lime-marly Platten which form the transition from the Permo-Carbon to the Permian system. The Permian system itself in Russia begins with coppery limestone and red-clays, on which directly follows the Zechstein-limestone. In Germany in the composition of Permo-Carbon equivalent to Artinsk and Kungur-Stufen, enter: Lebacher Schichten (in Saarbrücken), Brandschiefer (in Saxony), Kohlenrothliegendes (Bohemia).

To make it clearer I give the following scheme:

European Russia		Western Europe
Permian system	Zechstein Red-clay Coppery sandstone	Zechstein Rothliegendes, etc.
Permo-Carbon	Kungur-Stufe Artinsk-Stufe	Lebacher Schichten Brandschiefer Cuseler Schichten Kohlenrothliegendes, etc.
Carboniferous-Stufe	Fusulina and Schwagerina limestone, etc.	Productive Gruppe Kohlenkalk

As to the question whether Permian-Carbon belongs to the Carboniferous or the Permian system, that, from my point of view, is quite a matter of indifference. But we generally connect Permo-Carbon with the Permian system.[2]

July 24, 1909

[1] Krotow, *Artinskische Etage; Geol. Forschungen am West-Abhange d. Urals; Notiz auf d. Brief Herrn Nikitin über Permocarbon.*

[2] Letter of February 19, 1910.

THE FORM OF NANTASKET BEACH

DOUGLAS WILSON JOHNSON AND WILLIAM GARDNER REED, JR.

INTRODUCTION

This paper presents the results of a study of the form of Nantasket Beach, and includes a discussion of the stages of development through which the beach has passed to reach its present form, and of the processes by which that development has been accomplished. Our attention was directed to the Nantasket problem by Professor W. M.

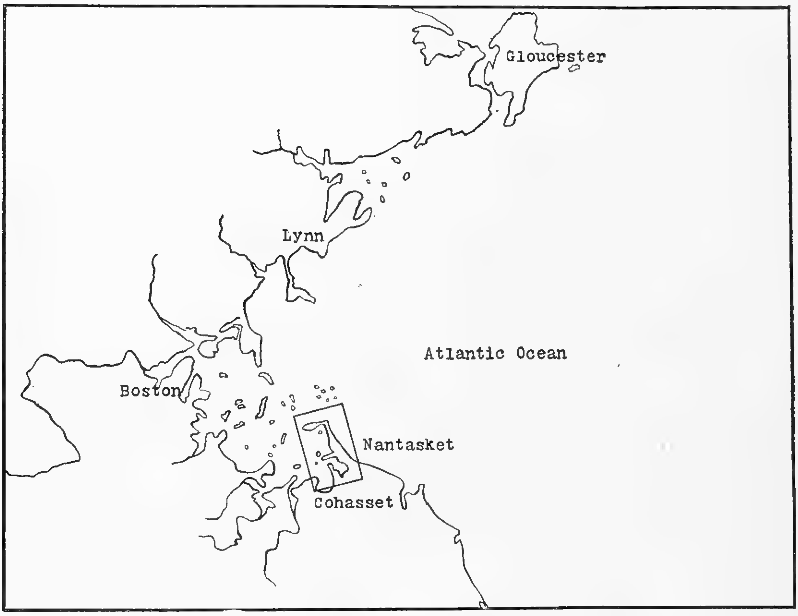

FIG. 1.—Location of Nantasket area.

Davis, who was the first to discover the significance of the abandoned marine cliffs and beaches, and their relation to islands which have long since disappeared. Acknowledgments are also due the Boston street commissioners for assistance in securing old maps for examination; to Mr. E. G. Knight of Hull for information regarding conditions prior to the building of the County Road on Nantasket

Beach; and to Mr. F. M. Hersey of Boston, and the officials of the United States Coast and Geodetic Survey for numerous courtesies. In addition to these gentlemen, our thanks are due to many others in Boston and Hull for various services.

Nantasket Beach lies at the southeastern border of Boston Harbor, separating that portion of the harbor from the Atlantic Ocean (Fig. 1). The name "Nantasket Beach" is generally applied to all of that irregularly shaped lowland between the rocky hill of the Atlantic on the south, and the drumlin known as Allerton Great Hill on the north, and is not restricted to that portion of the lowland immediately bordering the ocean at the present time. As thus defined Nantasket Beach has a width of from a few hundred feet to more than half a mile, and a length of a little more than three miles. In our discussion we include the neighboring district of Hull, as well as several outlying islands, which are more or less closely related to certain phases of our investigation.

THE PROBLEM STATED

A casual study of the Nantasket district makes clear the fact that Nantasket Beach consists of sand, gravel, and cobbles, deposited by wave action between several drumlins which formerly existed as islands. The problem which we have to consider may therefore be described as a problem in island-tying by means of beaches. The tying of islands to each other and to the mainland, by the formation of connecting beaches, has been recognized as a common phenomenon along a youthful shoreline of depression, where islands are apt to be more or less numerous. Boston Harbor occurs on a shoreline of depression, but the islands which help to form the harbor, and which are frequently connected with each other and with the mainland by beaches, do not as a rule represent the summits of hills left as islands by the depression of a maturely dissected mainland. They are for the most part typical drumlins, the trend of whose long axes indicates that the ice-sheet which fashioned them moved from the land southeastward out to sea. It is evident that drumlin islands might be formed along a shoreline of elevation; hence the phenomena about to be described might occur along both of the standard types of shorelines. The principles involved in our discussion remain the same, whether the islands be composed of solid rock or unconsolidated

glacial till; but it will appear that the stages of shoreline development are passed through more quickly, the wave-cut cliffs are more symmetrical, and the past conditions more easily reconstructed where drumlin islands are involved, as in the Nantasket case.

In the following pages we shall briefly review the principles of shoreline development, and then describe in some detail the present form of Nantasket Beach. On the basis of this description, and in view of the principles of shoreline development, we shall endeavor to reconstruct the initial form of the Nantasket district. Still guided by the principles of shoreline development, we shall next trace the successive steps in the development of Nantasket Beach from the initial form to the present form, with brief attention to the changes which will probably occur in the future. It will appear that Nantasket Beach is a very complicated example of island-tying, which illustrates in a remarkable manner the fact that shorelines are the product of systematic evolution according to definite physiographic laws.

LITERATURE

So far as we are aware, no detailed account of the physiography of Nantasket has been published. Professor W. O. Crosby (1893) has described the hard rock geology of the district just south of the beach in great detail and has considered the beach and drumlins at some length. He has also discussed the evidence of post-glacial changes of level in the Nantasket area. Other references to the district here described are found throughout the literature on the Boston Basin, but are not of importance in the present discussion.

In 1896 Professor W. M. Davis published a paper entitled "The Outline of Cape Cod," in which he discussed at some length the principles of wave and current action, and applied these principles in a study of the present form of Cape Cod and the past changes in the outline of the cape. The principles set forth in Professor Davis' essay are considered more fully on a later page.

Dr. F. P. Gulliver in a paper on "Shoreline Topography" (1899) has discussed at length various shore forms, including beaches which connect islands with the mainland or with each other. To such beaches he has applied the name "tombolo." Several types of

tombolos are described, and Nantasket Beach, which might be described as a complex tombolo, is briefly mentioned.

In common with all students of shoreline topography, we are indebted to Dr. G. K. Gilbert's classic studies of lake shores for the elucidation of many of the principles upon which all shoreline studies must be based.

A brief note on "The Geology of the Nantasket Area," containing an outline of the physiography of the district, was published by Professor D. W. Johnson in *Science* three years ago.

THE PRINCIPLES OF SHORELINE DEVELOPMENT

Physiographers recognize two distinct classes of shorelines—those formed by a (relative) elevation of the land, called shorelines of elevation; and those formed by a (relative) depression of the land, called shorelines of depression. It is not necessary to repeat the characteristic features of these two classes of shorelines, nor to trace the successive stages by which young shorelines of each class acquire, by the time they reach maturity, curves of a relatively simple pattern, marine cliffs more or less bold, and shelving beaches at the foot of the cliffs. Initial characteristics and stages of development are both set forth in our best textbooks on physiography.

We may note, however, that the processes of shoreline development involve both wave and current action. It has been shown that wave action is largely confined to the erosion of the land margins, to the transportation of the eroded material a short distance from the shoreline, and to the deposition of the material in the deeper water; and to the heaping-up of sand, gravel, and cobbles into long ridges or beaches, where the conditions favor wave building more than wave erosion. Current action, on the other hand, effects but little erosion, and is mainly effective in the 'longshore transportation of material previously eroded by the waves or brought in by rivers. It has been shown that the combined effects of these two processes is to produce, in time, a shoreline characterized by long, simple curves, and free from sharp angles or other irregularities. Headlands are cut back, or retrograded, and re-entrants are built forward, or prograded, in the attempt made by waves and currents to straighten out the initial irregularities of the shores, and thus to establish a

graded shoreline. The process is analogous to the formation of graded stream profiles by the degrading of elevations and the aggrading of depressions. If the waves cut back faster on one side of a headland than they do at the headland or beyond, and a strong current sweeps along the shore, the formation of a sharp angle at the headland is prevented by the prograding of the shore beyond the headland as rapidly as it is retrograded in the region of pronounced cutting. Thus, in the case of Cape Cod, Professor Davis has shown that the retrograding of the shore in the vicinity of Highland Light, due to active wave erosion, has been accompanied by a prograding of the shore farther north, where successive beaches have been built forward to maintain the simple curvature of a maturely graded shoreline. Equilibrium is reached, or the beach is maturely graded, when a gently curved or straight shoreline is developed; thereafter the headlands and beaches both retrograde gradually under the continued attack of the waves.

Inasmuch as the Nantasket problem involves a complex example of island-tying, we may here consider certain principles underlying the formation of connecting beaches, or tying bars as they are often called. If an island faces a large expanse of open water on which large waves are produced, and these waves come in general from one direction, the end of the island exposed to the brunt of the wave attack will be eroded, and the eroded material will be gradually drifted back along the sides of the island and strung out behind as a spit. In course of time the spit may reach the mainland or another island, and the island-tying is complete. Variations in local conditions may result in various forms of the tying bar; examples of several forms are described by Dr. Gulliver. It is possible that in some cases the bar may be built from the mainland out to the island (Gulliver, p. 192).

Backward tying is not the only form of island-tying to be observed along the shores. Lateral tying is certainly strongly developed in the Boston region, and we believe that many cases now regarded as examples of simple backward tying will prove to be more or less complicated examples of lateral tying. If wave erosion is most active on the eastern end of an island which lies at the mouth of a bay, and which is between two headlands situated to the north and south of

the island (Fig. 2), several types of tying may result under different conditions. If there is no pronounced current action except the on-shore and off-shore tidal currents and the movements of the water due to waves coming from the east, simple backward tying may result (*a*). Under the same conditions as those just outlined, provided that the shallowing of the water inland is favorable, the material eroded from the head of the island may be drifted backward but at the same time northward and southward in curving lines along a zone where the water is of such depth as to favor deposition before reaching the bay head. Similar deposits from the headlands would meet those from the island, and lateral tying by curved bars would result (*b*). These bars might then be prograded, as explained on a previous page, until they formed a nearly straight shoreline between the island and the headlands. If the tidal action were fairly strong, the bars from the island and headlands might not join, leaving each portion as a spit, possibly more or less irregular in form, at its free end (*c*). If a pronounced 'longshore current existed, the waves still coming from the east, the material eroded from the island by wave action might be transported by the current from the island toward the headland, building a bar which would eventually tie the island to the mainland (*d*). In a similar manner a bar built northward from the southern headland might effect the tying of the island to the mainland (*e*). A sufficiently strong tide might prevent the tying in either case by maintaining a tidal inlet. But if the tying were effected,

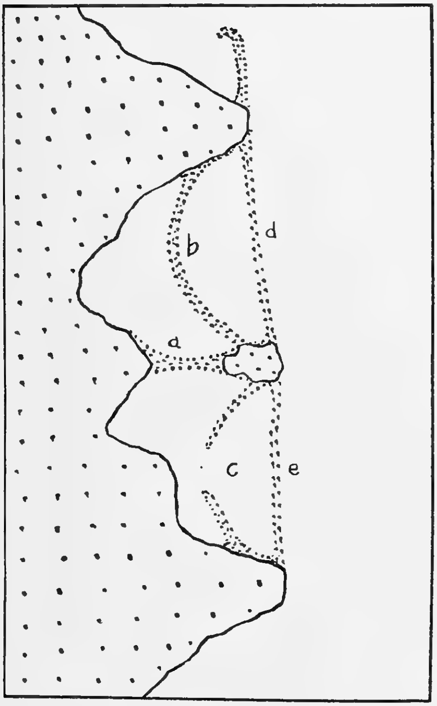

FIG. 2

it should be regarded as lateral tying, the connecting bar being built at right angles to the direction of wave attack, and parallel to the shoreline. Lateral tying similar to that represented by *d* and *e*, Fig. 2, might be produced if the character of the sea bottom caused the waves to break along the line *de* instead of entering the bay to the points *b* and *c;* also in case a barrier beach migrating toward the shore encountered the island and headlands in its progress.

If several islands instead of one were involved in the foregoing cases, more complex types of backward and lateral tying would result. Nantasket Beach represents a complicated case of both lateral and backward tying, involving for the most part prograded lateral tying bars of the types *b* and *c*, Fig. 2.

THE PRESENT FORM OF NANTASKET BEACH

The principal topographic features of Nantasket Beach are shown on the accompanying map (Fig. 8) based on a chart of Boston Harbor prepared by the United States Coast and Geodetic Survey (No. 246, C. & G. S. Boston Harbor, 1907). The larger features appear on the chart, but we have added the details of smaller beaches, wave-cut cliffs, etc. The irregular hills in the southern part of the map are composed of much altered sedimentary and igneous rocks which are very resistant and yield but slowly to the attack of the waves and weather. All other elevations on the map represented by contours are drumlins more or less eroded by wave action. The lower areas, including the lower ridges indicated by short hachures, are practically all of beach material; the exceptions consist of low areas of till between certain drumlins located close to each other, beach sand gathered into small dunes by the wind, and some deposits in swampy areas to be considered later. If we except the rock above mentioned, we may properly say that the features of the Nantasket region are due to marine action upon drumlins; for the effects of stream action and wind action are so slight as to be negligible.

The drumlins.—In describing the present form of the Nantasket drumlins it will be convenient to consider them in the order of their preservation from marine erosion. The letters in parentheses refer to the respective drumlins on the map, Fig. 8. The best preserved of the Nantasket drumlins is a small one called Hampton Hill (H),

located in the southern part of the region, back of the beach. It has been slightly cliffed by the harbor waves, on the southwest, but is otherwise practically in the same condition as when the ice left it. Nantasket Hill (N) at Hull, also called Telegraph Hill, is another drumlin which has suffered but little erosion; it is slightly cliffed on the south. Thornbush Hill (T), just west of Nantasket Hill, is somewhat more strongly cliffed, but retains its initial form to a marked degree. The erosion has taken place at the southwest side. Sagamore Head (Sa), near Hampton Hill, preserves a nearly perfect outline except for a pronounced cliff on the the northeast side and a minor cliff on the north and west. The main cliff is well back from the present shoreline, and has evidently not been touched by the waves for many years.

North of Sagamore Head is White Head (W), a drumlin which retains its initial form fairly well on the south, although a slight cliffing is noticeable there; but which has a remarkable strongly curved cliff cut into its northern side (Fig. 11), and smaller cliffs on the northeast and east. Like the northeast cliff on Sagamore Head, the cliffs on the north and east sides of White Head are well back from the present shoreline and have long remained untouched by the waves. West of White Head are several low drumloidal hills, connected by lower areas of till and cliffed on both the north and south sides. Great Hill (G), at Allerton, has a strongly marked cliff on the eastern end where the waves are still cutting into the hill, although not so effectively as formerly. There has apparently been a slight cliffing on the western end of Great Hill, also. Strawberry Hill (St), about half-way between Allerton and Sagamore Head, is in many respects the most remarkable drumlin in the district. Except for a short distance along the northwest side, it has been cliffed throughout its entire circumference; a rather inconspicuous cliff is developed along the north side, more prominent cliffs on the south and west sides, while the southeast face is a splendid marine cliff long ago abandoned by the waves (Fig. 3). In fact the only point where the sea still reaches the drumlin is along its southwest side. There is a marked escarpment on the northeast corner of the cliffed drumlin, but much of this is due to the removal of till for road-building. Professor Isaiah Bowman informs us, however, that a small nip existed there before

the excavations by man obscured the relations. It should be noted that the abandoned cliffs of Sagamore Head, White Head, and Strawberry Hill do not face in the direction of the present shoreline, but make pronounced angles with that shoreline, as shown by the map.

Quarter Ledge (Q) at Hull is a more than half-consumed drumlin, the marine cliff facing northward. Little Hill (L) at Allerton is of special interest because it is evidently but a small remnant of a drumlin (Fig. 10) on the northeast of Great Hill. It would doubtless have

FIG. 3.—Strawberry Hill, from the south, showing abandoned marine cliffs; the higher cliff faces southeast.

been completely removed by the waves ere this but for the protection afforded by a stone sea-wall constructed north and east of it to prevent its complete destruction. Skull Head (Sk) represents the final stage in the series, having been completely destroyed. This drumlin was situated to the northwest of Strawberry Hill, and so far as we can tell was probably of small size. It was apparently nearly destroyed by wave action from the west, the last remnant being removed by man and used as road material. Those who remember this drumlin remnant agree in describing it as having a gentle slope toward the east and a steep cliff facing west. The presence of great

bowlders near the supposed former site of this drumlin, the shape of the associated beaches, and the westward protuberance of the shoreline northwest of Strawberry Hill confirm the descriptions and location of the drumlin given by the inhabitants.

West of Nantasket Beach there are many drumlins more or less cliffed by marine erosion. On Nantasket Beach are drumlins in all stages of marine erosion, from slight cliffing to almost complete destruction. East of Nantasket Beach no drumlins are encountered. The suggestion is very strong that the sudden cessation of drumlins to the east is due to the complete removal of formerly existing drumlins by marine erosion. As will appear later there is strong evidence in favor of this interpretation.

The beaches.—Under this head are described the various spits, connecting bars, beaches, etc., both ancient and recent, which make up the composite feature called Nantasket Beach.

The beaches at Hull present no striking characteristics. The cliffed drumlins of Nantasket Hill, Thornbush Hill, and Quarter Ledge are close together, connected by lowland areas of till, and the cliffed portions are bordered by a narrow, sometimes bowldery beach. A sand spit, called Windmill Point, is strung out toward the west, probably under the influence of tidal currents passing through Nantasket Roads. This group is connected with Allerton by a bar believed to be the result of simple backward tying from Great Hill and Little Hill. The appearance of a **Y** bar is due to a railroad embankment built across the end of the bay back of Great Hill in order that the track would not have to be placed in the very exposed position on the seaward side of the Allerton drumlins. The protuberance of beach material from the northwest side of Great Hill is explained later.

From Allerton Great Hill on the northwest to the rock hills of Cohasset on the southeast a relatively straight beach borders the present shoreline. Back of this modern beach one observes parallel ridges of sand, gravel, and cobbles, in all respects similar to the higher part of the present beach which is still being acted upon by the waves. Still farther back the ridges become less prominent, until in the central areas of the Nantasket lowland they are scarcely perceptible. Moreover, they are no longer parallel to the modern

beach, but are strongly curved, concave toward the east. At the extreme west, however, these curved beaches become prominent features once more and are as high in places as the modern beach.

If we examine the older beaches more carefully, we note several significant points. Just south of Allerton Great Hill the high and prominent westernmost beach, which we may call West Beach, is intersected by the modern beach. West Beach does not touch Great Hill and from the curvature of the beach it seems hardly probable that it connected with the former seaward extension of Great Hill. At its southern end West Beach ties to the northwest side of Strawberry Hill, just in front of the only part of the hill which has no bordering marine cliff. From the western side of the beach projects the protuberance of the Skull Head area, which destroys the otherwise symmetrical curve given to this portion of the harbor shoreline. Of the beaches which intervene between West Beach and the modern beach, a few connect with Strawberry Hill, others curve eastward as if to connect with something formerly situated in front of Strawberry Hill, and still others pass in front of the hill to connect with White Head or Sagamore Head farther south; while at the north all converge toward the intersection of West Beach with the modern beach, merging with the former or being cut off by the latter. The waves from the harbor are now attacking West Beach north of Skull Head, giving it a steeper western face, cutting off part of the western convexity, and building a small subsidiary beach toward the north. This attack of the harbor waves upon a beach formerly constructed by the powerful Atlantic waves has become so effective that sea-walls have been built in places to prevent further destruction of the old beach.

South of Strawberry Hill the relations are much the same, except that the beaches are less distinct and less regular in outline. The equivalent of West Beach does not connect directly with Strawberry Hill, but is truncated by a more recent beach or spit which extends southward from the southwest end of the great cliff on Strawberry Hill. The older main beach curves rather strongly southwest, continues south and southeast in much broken and complicated ridges, and finally spreads out in a broad, indefinite plain of beach material near the western end of White Head. The most prominent beach in this vicinity is one which extends from the eastern point of Straw-

berry Hill to the eastern end of White Head, and on which the County Road is located for much of the distance between the two hills. Both east and west of the County Road Beach are some fairly well-marked beaches, more or less obscured by sand dunes, especially toward the east. Two of the older beaches between White Head and Sagamore Head are especially prominent, and are practically straight. Both north and south of Strawberry Hill the beaches in the central areas, midway between the drumlin hills, are often so low and indistinct as to be nearly or quite imperceptible. In places the detection of the beaches is made easier by a difference in the grass and other vegetation growing on the beach ridges and in the intervening depressions.

THE INITIAL FORM

In our attempt to reconstruct the initial form of Nantasket Beach, we have appealed to three sources for information: (1) Some of the older inhabitants who recall the appearance of the beach in earlier days; (2) Old maps and charts of the region; (3) The principles of shoreline development applied to the interpretation of the present forms.

Shoreline changes take place with comparative rapidity, and in some cases a man may live to see profound alterations in the outline of the coast on which he lives. Some residents of Nantasket speak of a time when the sea used to come in to the present location of the County Road. It must be remembered, however, that people are apt to be impressed by the unusual, and that some long-past transgression of exceptional storm waves far across the present beach may be responsible for the impression that the sea is now farther removed from the road than it was fifty years ago. As late as 1898, during the "Portland Storm," breakers crossed the railroad track, which is well back from the present beach. In regard to the former location and general appearance of the remnant of Skull Head drumlin, now completely lost, the descriptions of the older inhabitants agree fairly well, and are corroborated by the physiographic evidence.

The old maps and charts of the region afford some evidence as to the general outline of the beach in earlier years, but prove to be too inaccurate to justify any conclusions as to recent changes in outline. A chart prepared by the United States Coast and Geodetic Survey in

1846 differs in minor points from the more recent charts of the same area, and a comparison of the two might be expected to show changes in the shoreline since 1846. Indeed, such a comparison has been made in connection with a study of cliff retreat at Allerton Great Hill and an estimated retreat of about two feet a year has been inferred on the basis of the comparison. A careful study of the two charts in the light of the geological features of the region makes clear the fact that one or both of them are too inaccurate to warrant any conclusions as to changes in shoreline based on such evidence. For example, it appears from the charts that the shoreline along the southeastern corner of Allerton Great Hill is farther east today than it was in 1846. Now the shoreline at this point is formed by the cliffed face of the hill, and since this hill is a drumlin which could not have been built forward since the glacial epoch, the charts are manifestly not sufficiently accurate to be used in determining recent changes in shoreline. On the other hand, it should be noted that the chart of 1846 indicates a shoreline so nearly like the present shoreline as to warrant the conclusion that the sea has not been materially closer to the County Road in the last sixty years than it is today, except during unusual storms. Indeed, a chart of Boston Harbor published in the fourth part of *The English Pilot* in 1709, while not accurate in details, seems to show that no pronounced changes in the shoreline of Nantasket Beach have occurred in the last two hundred years.

The application of the principles of shoreline development to the interpretation of the present form of Nantasket Beach offers the only means of determining the initial form of the beach. We believe that by this means it is possible to determine with a fair degree of certainty the geography of the Nantasket region before the present beach came into existence. The problem involves the restoration of the lost drumlins of this portion of Boston Harbor.

There is little difficulty in the restoration of those drumlins which retain their initial form to a considerable degree. The existing drumlins of the Boston district are of the same general type, none of them resembling the greatly elongated type found in some parts of New York. It is possible, therefore, to complete the outlines of Thornbush Hill (T) and Nantasket Hill (N) at Hull, Great Hill (G), Strawberry Hill (St), White Head (W), Sagamore Head (Sa), and Hampton

Hill (H) without danger of appreciable error. This has been done in Fig. 4, the restored portions being indicated by broken lines. Where more than half of a drumlin has been destroyed, the restoration cannot be made with the same degree of certainty, and we recognize that the location and size of such drumlins cannot be determined with absolute precision. The margin of error is not so large as materially to affect our problem, and the restorations of Quarter Ledge drumlin (Q) and Allerton Little Hill (L) in Fig. 4 (restored portions in broken lines) are believed to be essentially correct. The position of Little Hill will account for the peculiar protuberance of beach material northwest of Great Hill, if we agree that a spit trailing back from Little Hill by the action of waves and currents through Nantasket Roads would have a form somewhat similar to that of Windmill Point (WP) in Fig. 8. The restoration of the drumlins which are wholly destroyed involves a larger chance of error, and each individual restoration of this kind must be carefully considered.

The first restoration of a drumlin now completely destroyed (complete restorations shown by dotted lines) is that of Allerton Lost Drumlin (AL). That this drumlin formerly existed is shown by the relations of West Beach. The beach does not connect with Great Hill at the present time, but is abruptly cut off by the present shoreline a short distance south of Great Hill. That this beach formerly continued toward the east seems clear. It is equally clear that the seaward continuation of the beach would not connect with the seaward continuation of Great Hill, unless we imagine the beach to have been bent sharply northward. This last assumption is contrary to what we should expect in a beach as well developed as West Beach, has no evidence to support it, and is one which we are not permitted to make arbitrarily.. The precise location of the drumlin with which West Beach must have connected cannot be determined with certainty, nor can its size be inferred; but that it occupied some such position as is indicated in Fig. 4 there would seem to be little doubt. It is not permissible to consider West Beach connected with the eastward extension of Little Hill, for this would require a marked northward bend in the beach, or the reconstruction of Little Hill on too large a scale.

It will be convenient to consider the restoration of Skull Head

drumlin (Sk) next, as certain features connected with it will aid us in other reconstructions. The location of this drumlin is made clear, as already noted by the peculiar protuberance back of West Beach northwest of Strawberry Hill, by the occurrence of large bowlders along the shoreline at this point, and by the historical evidence. That the drumlin was small is indicated by the fact that it has been completely removed, although in a relatively sheltered position, and by the further evidence that this removal was accomplished mainly by the harbor waves, it being stated by those who remember the drumlin that the eastern slope was not cliffed, while the western face was a distinct marine cliff. The last remnant of this drumlin was removed by man in recent years. The location and size of Skull Head drumlin are believed to be essentially correct.

An examination of the great southeast cliff on Strawberry Hill shows that the cliff was formed by waves coming from the southeast, and not from the northeast, the direction of the present wave attack. The fact that a sharp angle on the cliffed drumlin projects forward on that part of the hill which would be most exposed to the direct attack of the waves had no other drumlin existed in front of it to protect it, confirms the opinion that the restoration of a drumlin must be made in the vicinity of the shallow area off-shore known as Strawberry Ledge. This we have called the Strawberry Lost Drumlin (SL). As will appear later, the former presence of a drumlin at this point accounts for the northeastern angle (recently blunted by excavations for road material) of Strawberry Hill, the small amount of cliffing on the north side of the hill, the eastward curve of the beaches northeast of the hill, the direction of the splendid southeast cliff, and a certain feature of West Beach to be considered in the next paragraph. Whether the shallow area at Strawberry Ledge has any connection with the Strawberry Lost Drumlin we are unable to say, but that the drumlin must have been located near this spot seems clear.

As has already been noted, Skull Head drumlin (Sk) was apparently not cliffed on the east, or was so slightly cliffed as not to attract the attention of persons who did notice the cliffing on the west. Yet this drumlin must have occupied a position fairly well exposed to the waves of the Atlantic, unless some protection from those waves was afforded by drumlins or beaches farther east. It should be noted

also that West Beach is unusually high and broad, the modern beach at the east alone showing the same strength of development. In order that the waves should build a beach so extensive and so well developed, they must either have acted on the ancient West Beach shoreline for a long period of time, or must have been rapidly supplied with an immense amount of material previously reduced to a condition ready for beach construction. That the waves did not act for a long period of time in the vicinity of the ancient West Beach shoreline is shown by the absence of any considerable cliffing on the east end of Skull Head drumlin and the north side of Strawberry Hill. It is evident, moreover, that the large amount of material in West Beach could not have been supplied by the cliffed portions of the existing drumlins in that vicinity so it must have come from drumlins long ago destroyed, or from the sea bottom. We believe that the most probable condition which will account for all the facts is the former existence of a beach or series of spits more or less completely closing the space of open water between Strawberry Lost Drumlin and Allerton Lost Drumlin, thus forming a barrier which protected Skull Head drumlin and Strawberry Hill from wave action. The construction of this barrier was probably facilitated by the existence of another drumlin in the vicinity of the shallow area east of Bayside, and we have called the restoration of this drumlin (Fig. 4) the Bayside Lost Drumlin (BL). As will appear in the next section, the present relation of beaches and cliffs strongly suggests that a drumlin located in the vicinity of the Bayside shallow maintained the barrier so long as any part of the drumlin remained; but that with the complete removal of the drumlin the barrier was broken through, the accumulated débris swept rapidly back to the present position of West Beach, still protecting the east end of Skull Head drumlin but exposing a large part of the north side of Strawberry Hill to the waves which formed the low cliff we observe today.

The highly peculiar character of the cliffing on the north and northeast sides of White Head drumlin can be explained only by the restoration of a drumlin northeast of White Head. This we have called the White Head Lost Drumlin (WL). Its precise location cannot be determined, but it must have been close enough to White Head to control the marked curvature of the White Head cliff and the

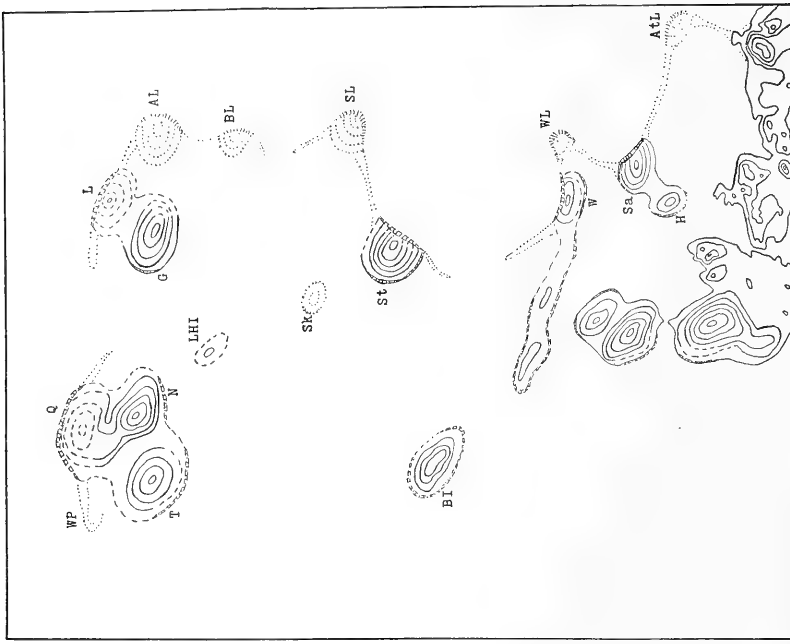
AL
BL
SL
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FIG. 5


AL
BL
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AtL
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H
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SK
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FIG. 4

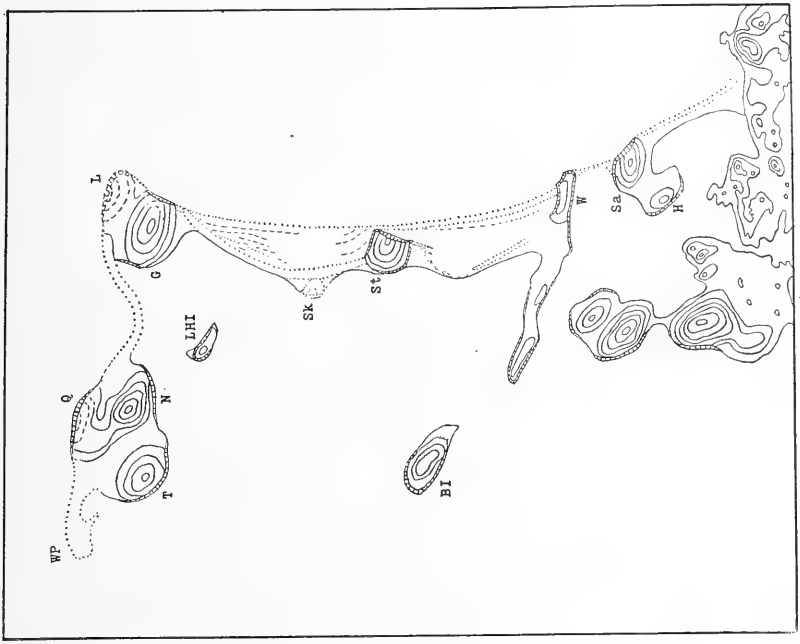

FIG. 7

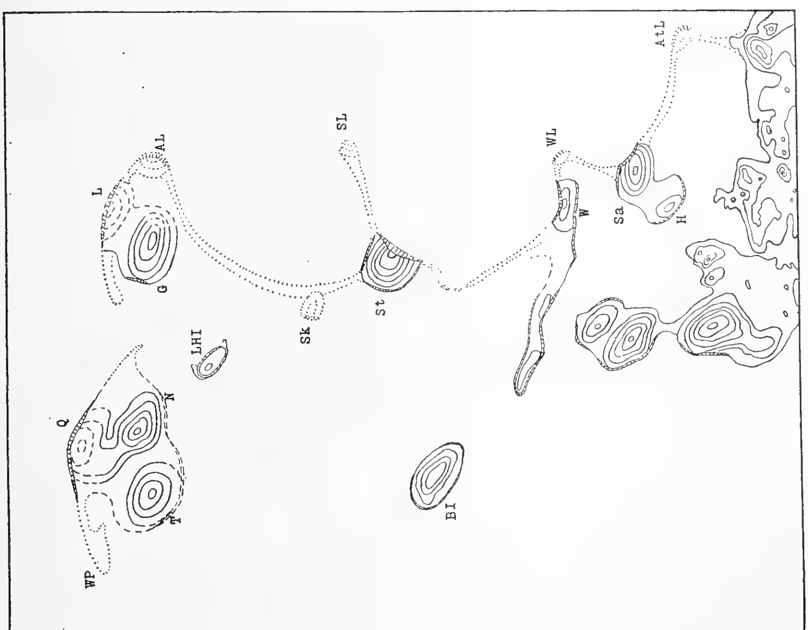

FIG. 6

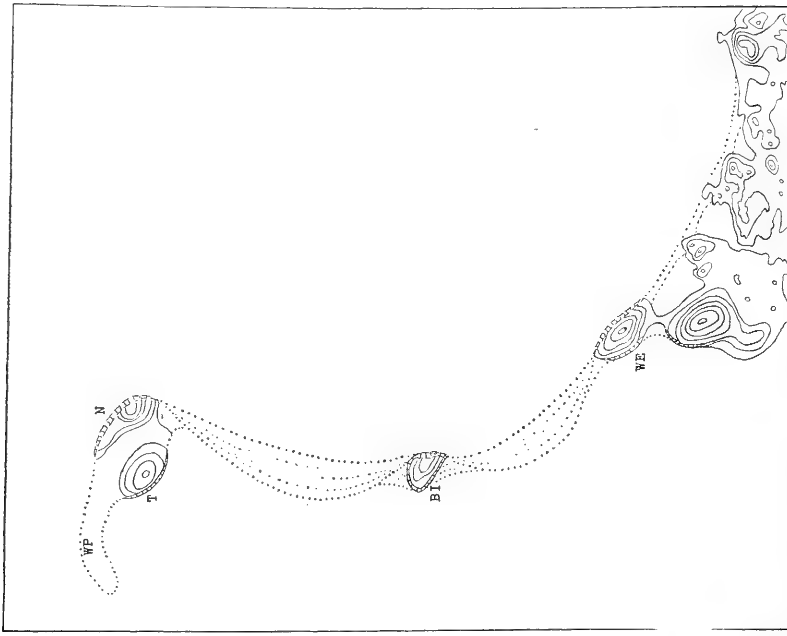
N
T
WP
BI
WE

FIG. 9

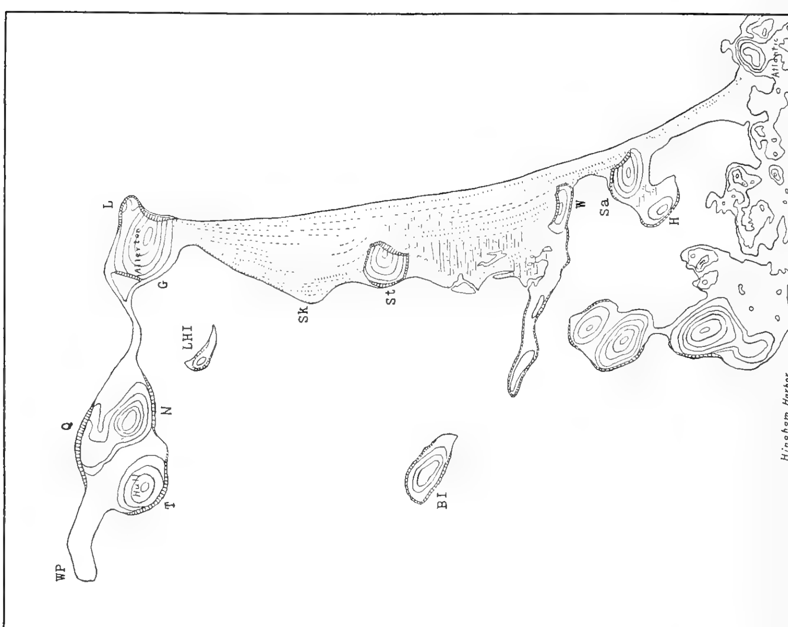
L
Allerton
G
SK
St
W
Sa
H
Atlantic
LHI
Q
N
Hull
T
WP
BI
Hingham Harbor

FIG. 8

less marked but distinctly curved cliff on the northeast side of Sagamore Head. The position assigned to it in Fig. 4 cannot be far from correct. The character of the Sagamore Head cliff, just referred to, necessitates the restoration of another drumlin to the southeast. Unless this drumlin existed somewhere in that region, affording protection to the southeast corner of Sagamore Head, it is difficult to understand why the latter was not cliffed directly from the east, and why the cliff is concave instead of convex. A shallow area north of Atlantic Head may have been the location of this drumlin as shown in Fig. 4. It is possible, however, that it may have been nearer Sagamore Head. We have called this restoration the Atlantic Lost Drumlin (At L).

This completes the restorations which seem required by the present forms of cliffs and beaches. That other drumlins may have existed in the region is, of course, possible; although the former existence of many more in the immediate vicinity of the Nantasket area would doubtless be indicated by peculiar alignments of cliffs on the remaining drumlins, or by the relations of the beaches. That additional drumlins may have existed still farther east is quite possible, but the data necessary for the reconstruction of such easternmost drumlins would be recorded only on drumlins and in beaches since completely destroyed. So far as the present problem is concerned the conditions shown in Fig. 4 may fairly be taken to represent the initial one of a series of developmental stages which we will now endeavor to follow until the present form of Nantasket Beach is reached.

THE DEVELOPMENT OF NANTASKET BEACH

In Fig. 5 we have endeavored to represent the conditions which probably existed in the Nantasket region at a much later stage than Fig. 4. The Allerton, Bayside, and Strawberry Lost drumlins have been much eroded by the waves and the material removed from them has been built into spits or connecting bars, which together with the remaining portions of the drumlins form a barrier to protect the east end of Skull Head drumlin and the north side of Strawberry Hill from any appreciable erosion. From Strawberry Lost Drumlin a bar ties backward to Strawberry Hill, protecting the northeast corner of the hill and helping to determine the direction of the wave attack which

is producing the southeast-facing cliff. That Strawberry Hill and White Head were exposed to strong wave action while Skull Head and Great Hill were well protected is evident from the splendid development of the ancient marine cliff on the two former. White Head Lost Drumlin is much eroded, but still serves to determine the character of the cliff on the north side of White Head, and at the same time effectually to protect the eastern end of the same. Sagamore Head has been cliffed on the northeast, the character of the cliff being

FIG. 10.—Little Hill, the remnant of an almost completely consumed drumlin.

determined by the position of White Head Lost Drumlin and Atlantic Lost Drumlin, and the bars tying back from them. Atlantic Lost Drumlin is much eroded, and in addition to being connected with Sagamore Head has a short bar connecting with the rock cliffs just south.

Allerton Little Hill and Quarter Ledge drumlin, facing the main channel to the north, have been considerably eroded, while even the better-protected drumlins have, as a rule, been cliffed slightly, especially on their more exposed sides.

It is evident that some latitude is allowable in the restoration of

certain of the features shown in the figure, without affecting the validity of the general interpretation here set forth. For example, the precise shape and location of the sand spits cannot be ascertained; and Atlantic Lost Drumlin might be nearer Sagamore Head, in which case the long bar connecting the two might be altogether absent, or represented by short spits or a short bar. We have indicated, however, those conditions which we consider most probable and the main features of the drawing are believed to be essentially correct.

Fig. 6 represents a later stage than Fig. 5. The complete destruction of Bayside Lost Drumlin has allowed the material formerly accumulated in its vicinity to be swept back to the Strawberry Hill–Skull Head region, and to be rapidly constructed into the prominent West Beach. At the north this beach still connects with the remaining portion of Allerton Lost Drumlin, thus accounting for the failure of this beach to touch Allerton Great Hill, a relation which is very distinct at the present time. At the south the connection with Strawberry Hill was far enough west to allow a slight cliffing along much of the north side of the hill. The absence of a pronounced cliff at the northeast corner of Strawberry Hill previous to recent excavations, and the eastward curve of some of the old beaches northeast of the hill (Fig. 3) indicate that a remnant of Strawberry Lost Drumlin still survived at the period represented by Fig. 6 and even later, preserving the backward-tying bar until West Beach was considerably prograded. Between Strawberry Hill and White Head spits or a curved bar nearly or quite close the space of open water, although the irregular character of the gravel ridges now observable at this point suggests that the bar may have been repeatedly broken through during heavy storms. The retreat of the shoreline on the southwest side of Strawberry Hill has caused the older beach ridge to be truncated by a sand spit now forming. Other minor developments are indicated, including the continued cliffing of various hills, and the growth of Windmill Point and other smaller spits.

In the stage represented by Fig. 7 the present characteristics of Nantasket Beach begin to be more easily recognizable. Allerton, Strawberry, White Head, and Atlantic Lost drumlins have all been completely removed. Prograding has gone on actively in the two re-entrant curves north and south of Strawberry Hill, the shorelines

thus migrating eastward until a single beach describes a very gently concave curve from Allerton Little Hill to White Head. That the process of prograding was relatively rapid is indicated by the small size of the beaches in the inland areas north and south of Strawberry Hill. In places these beaches are almost imperceptible, and south of the hill it seems probable that the change in the position of the eastern shoreline from the westernmost beach to the County Road Beach was made without the formation of complete intermediate beaches. That the prograding had proceeded quite far, in the northern re-entrant at least, before the removal of the bar connecting Strawberry Hill with Strawberry Lost Drumlin, is shown by the development of faint beaches just north of the hill, curving eastward so strongly that they would pass in front of the restored portion of the hill if they were prolonged. These beaches must have been formed before the bar was destroyed. After the complete removal of Strawberry Lost Drumlin and the destruction of the bar, the ends of these beaches were eroded, as shown in Fig. 7, and the eastern angle of Strawberry Hill was slightly cliffed by the waves. In this manner the portion of the shoreline which had been prograded with reference to the Strawberry Lost Drumlin and bar, was retrograded until brought into harmony with the conditions existing after the destruction of drumlin and bar. Before the waves could seriously affect the the corner of Strawberry Hill the prograding of the entire beach (from Allerton Little Hill to White Head) as a single unit carried the shoreline eastward beyond the base of the hill. The prograding of the beach appears to have been connected with the retrograding of the headlands at Allerton and the removal of Whitehead and Atlantic Lost drumlins. As Allerton Lost Drumlin, Little Hill, and Great Hill have been cut back, the beaches to the south have been built forward, the point of no change, or fulcrum, being just south of the east end of Allerton Great Hill. The lack of a complete series of beaches south of Strawberry Hill may be connected with a more sudden westward migration of the southern end of the shoreline upon the disappearance of Whitehead and Atlantic Lost drumlins, and a consequent sudden eastward movement of the zone of wave building just north of Whitehead drumlin. As soon as the eastward migration of the beaches allowed the shoreline to clear the hill, the successive

beaches appear to be more or less continuous from Allerton to Whitehead. The remaining changes indicated on the drawing need but little comment. The removal of White Head Lost Drumlin, together with the formation of the County Road Beach, has resulted in the cliffing of White Head on the east and northeast, while the removal of the Atlantic Lost Drumlin has allowed the connecting bars to swing back and form a single bar which unites with the rock cliffs at Atlantic Head.

The next stage in the development of Nantasket Beach is that of the present, represented in Fig. 8. The principal change from the preceding stage consists in the prograding of the beach until it makes an unbroken, gently curved shoreline from Great Hill to Atlantic Head; the further cliffing of White Head at the eastern end and the abandoning of the cliffs on White Head and Sagamore Head by the waves as the shoreline migrated eastward; the complete removal of the Skull Head drumlin, partly within recent years; the filling-in of the small bay on the south side of Windmill Point, largely within historic times; and further erosion of all the drumlins still exposed to wave action.

In Fig. 9 we have attempted to represent a possible future stage in the development of Nantasket Beach. At the present time the most effective wave erosion is concentrated upon Great Hill and the small remnant of Little Hill. But these hills control the future of the beach, the erosion of the rocky mainland at the southern end being so slow as to be practically negligible. Heretofore the retrograding of these hills has caused the prograding of the beach; at the present time, however, a condition of equilibrium prevails, and a further cutting-back of the hills must result in a cutting of the beach also. With Great Hill gone, the beach would connect Nantasket Hill, Little Hog Island, Strawberry Hill, White Head, and Sagamore Head. Strawberry Hill would be at an exposed angle of this beach and would soon be destroyed. Little Hog Island and White Head would be more exposed than before, providing the former had outlasted Strawberry Hill. Sagamore Head and Hampton Hill would take their turns in controlling the position of the beach until completely reduced by the wave attack. The drumloidal extensions west of White Head and the Hull district at the north will be the last remnants of Nan-

tasket Beach to survive, and of these two the Hull district will probably last much longer. If this interpretation is essentially correct, the relations in the Nantasket region will, in the remote future, resemble those indicated in Fig. 9. It is possible that the connecting bars may be broken through by the sea in one or more places, and that sand spits may replace the bars here shown. This will depend on local conditions of water depth and other factors which cannot be predicted.

FIG. 11.—Whitehead Drumlin, showing concave marine cliff on north side.

At present the area here shown is shallow, and favors the building of bars as indicated.

The protection of Great Hill is the key to the preservation of the entire Nantasket Beach district. A sea-wall has been constructed for the preservation of Little Hill, and this, of course, means protection to the adjacent areas of Great Hill. By such protective measures man may indefinitely postpone the normal changes which Nature would effect in the Nantasket area. It is interesting to note that man has begun his work in controlling the development of Nantasket Beach just at the time the beach has reached the greatest size which Nature could probably give it. Heretofore the beach has been increasing in

area. Hereafter the normal development of the beach, unless arrested, would result in decreasing its area.

CHANGES OF LEVEL IN THE NANTASKET AREA

Much has been written concerning possible elevations and depressions of the Massachusetts coast since the glacial epoch. The evidence is often unsatisfactory and contradictory, but is thought by many to indicate a gradual subsidence at the rate of approximately one foot in one hundred years. Professor Crosby believes that some of the drumlins, which now show no marked cliffs facing toward the Atlantic, were strongly cliffed before Nantasket Beach was completed, and that subsidence has carried these cliffs under water. "This view relieves us of the necessity of imagining a cordon of drumlins outside of the present beach which have been completely washed away, although it is not improbable that Harding's Ledge and the Black Rock Islets are the foundations of such vanished drumlins" (Crosby, p. 170). As we have shown above, there is abundant evidence that a number of drumlins did formerly exist outside of the present beach, and that these drumlins and their associated bars and spits effectively protected drumlins back of them from erosion. No subsidence is required to account for the lack of cliffing on the eastern ends of drumlins back of the present beach, and no evidence of submerged marine cliffs has ever been found.

It seems to us quite possible that there may have been a considerable depression in the Boston region since the glacial epoch; and that there may have been a very recent depression *of small amount* at the calculated rate of one foot in one hundred years. But that there has been any marked change in the relative position of land and sea during the last thousand years or more seems to us absolutely incompatible with the evidence furnished by Nantasket Beach. West Beach, as has already been pointed out, is similar in size and elevation to the beaches being formed along the present eastern shore of the Nantasket area. Had there been marked depression since the formation of West Beach, that beach would now be very low, possibly completely submerged. Had marked elevation occurred, West Beach should be relatively high, and other evidences of elevation should appear along the western margin of this beach. The close

similarity between the oldest and latest beaches in the Nantasket area proves that the sea stood at about the same height when the two were formed. The intervening beaches are often low, because of the rapidity with which the shoreline was prograded for a time; but County Road Beach is strong and high, and may be compared with West Beach and the recent beaches.

The duration of this still-stand of the land may be roughly calculated. Judging from old maps, there has been no marked change in the width of Nantasket Beach during the last two hundred years. Judging from the rate of cliff cutting in various drumlins in the vicinity of Boston as determined by surveys extending over forty years or more, the length of time required for the removal of those portions of drumlins which have disappeared since the early cliffing of Strawberry Hill and Whitehead and the formation of West Beach, with liberal allowance for relatively rapid cutting of drumlins well exposed to the sea, could scarcely have been less than one thousand years, and was probably two or three thousand years. We conclude, therefore, that there have been no marked changes in the relative position of land and sea in the Nantasket area during the last thousand years at least.

CONCLUSION

The form of Nantasket Beach presents a variety of complicated phenomena which, when carefully studied, enable us to reconstruct with reasonable certainty the history of the development of the beach. It appears that the present form of the beach is not due to the accidental tying-together of a few islands without system, but represents one stage in a long series of evolutionary changes which have occurred in orderly sequence and in accordance with definite physiographic laws. Perhaps nowhere in the world can features of beach development be better studied than in the area here under investigation. Certainly nowhere in the literature is recorded an example of so complicated a shoreline preserving the records of its past development with such fidelity.

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THE AGE OF THE EARTH AND THE SALTNESS OF THE SEA

H. S. SHELTON

Since the discovery of radioactivity, any estimation of geologic time from the process of secular cooling, or from calculations of the age of the sun's heat has become a process of very doubtful validity. That being so, enhanced interest now accrues to any method not based on these data. One of the most instructive of these is that of Professor Joly[1] based on the saltness of the sea. But, standing as it does on its own merits, and without collateral support, it is more than ever necessary to examine carefully the foundations on which it is based.

The analysis of rocks shows clearly that the proportion of sodium in the sedimentaries is much smaller than in the igneous rocks. The natural inference from this is that the balance is to be found in the ocean in the form of salt. Assuming these premises and a fairly uniform rate of erosion, the estimation of geologic time is reduced to a process of simple division. It is only necessary to find the total quantity of sodium in the sea and the amount brought down by the rivers each year. This, with some corrections, is Professor Joly's method. The corrections, according to his estimate, are not considerable and his calculation works out to something less than 100 millions of years.

The data for the two principal premises are derived from Sir John Murray.[2] This worker has carried out numerous investigations on ocean depths and has also made estimates of the amount of solvent denudation. That these are in the main fairly accurate can hardly be disputed; but, as applied by Professor Joly to an entirely different purpose, they are open to a number of criticisms.

For our present purpose we will accept Sir John Murray's estimate of the amount of the sodium in the sea; but the amount which enters

[1] *Trans. Royal Society Dublin*, Vol. VII, pp. 26 f.

[2] See *Scottish Geographical Magazine* (1887), and elsewhere.

into it each year is a much more doubtful quantity. Into all the sources of error it is not possible to enter here; but the following short summary will show that these are very great.

In the first place we must remember that sodium is a minor constituent in river waters. It is also, as every chemist knows, the most difficult of all to determine. Anyone who is acquainted with the many possibilities of error implicit in the process of boiling down considerable quantities of river water, removing all the other constituents in order to find in the end possibly two or three parts per million of sodium, will know that very little reliance should be placed on this part of an ordinary water analysis. In order to obtain results of any value for this constituent, great care and special precautions must be taken. So far is this from being the case in the average analysis, especially the older ones from which Sir John Murray's tables are constructed, that all the alkali metals are commonly determined together and stated as sodium and potassium.

Once more, Professor Joly makes an entirely inadequate allowance for cyclic salt. Sea salt, especially in stormy weather, continually passes into the air, is brought down by the rain, and is deposited in other ways. This is washed into the rivers and thus reaches the sea once more. Another form of cyclic salt is that known as fossil sea salt. This was deposited with the other constituents in the sedimentaries and is once more set free by erosion. As none of the ordinary rocks (with the exception of salt beds) contain any appreciable proportion of chlorine, it is highly probable that the greater part of the chlorine in river waters is cyclic in some form or other. This particular aspect has already been the subject of some controversy, and Professor Joly has admitted that he has probably underestimated the amount of cyclic salt; but he meets the difficulty by stating that there is a considerable preponderance of sodium in the river waters above the chlorine, and that, even assuming that all the chlorine is cyclic, the estimate of geologic time is not thereby raised to more than one hundred and forty millions of years.[1]

But, by this admission, the whole calculation is made to rest to a much greater extent on the minute accuracy of sodium analyses, which, as we have already seen, does not exist. To show what differ-

[1] See discussion between Professor Joly and Mr. Acroyd, *Chemical News* (1901).

ences small errors can make, it is interesting to note that more recently another worker, M. Dubois, has made fresh calculations, using only the more accurate sodium analyses, and has obtained as the result four hundred millions of years.[1] I, for one, should not like to state dogmatically that one or other of these results is accurate; but certainly the calculation of Professor Dubois is the more reliable of the two. It is more instructive to note the reason why such diverse estimates are possible. This can be seen by anyone who refers to the original paper and makes a few simple calculations.

According to Sir John Murray's data, the percentage of sodium in river waters compared with the total dissolved solid is 3.47, that of chlorine 1.85.[2] Professor Joly's calculation assumes 10 per cent. of the chlorine to be cyclic. If we assume the amount of sodium to be 2.47 per cent. (an amount of error not at all unlikely to occur in these analyses, especially if calculated in a rough statistical way), and the more probable quantity of 90 per cent. of the chlorine to be cyclic, our estimate would be raised to two hundred and fifty millions of years. If the sodium were but 1.5 per cent. of the total solid, the estimate would be fifteen hundred and seventy millions of years. As we have seen, M. Dubois' estimate was four hundred millions of years, but he has reached such a point in the calculation that a very small error would make a great difference in the result. From such considerations as these we can understand the uncertainty of any such estimate on present data. It is to be hoped that, in the future, chemical analysts will pay special attention to this problem of the proportion of sodium, and that, in this way, more accurate data may be obtained.

Nor must it be assumed that, however accurate may be the data, this problem can be regarded as solved. There still remain a number of theoretical objections. The method assumes approximate uniformity in this process of the conveying of sodium to the sea. It also assumes that the sodium which reaches the sea never returns to the sedimentaries. Neither of these assumptions, though probable, can be regarded as established. Our knowledge of geological chemistry is certainly not sufficient to enable us to say that none of the

[1] *Proc. Amsterdam Academy* (1902).

[2] See Clarke, *Data of Geochemistry*, p. 88.

sodium in the sedimentaries had its origin in the sea. Then the problem of salt beds must also be considered. That a considerable proportion of the salt deposited in lakes is cyclic, and had its origin in the sea may be regarded as established. But what would happen if such a salt bed were subject to metamorphic action? It is obvious that not only would the sodium enter into the composition of the metamorphic rock, but that it would do so out of all proportion to the chlorine. Such a volatile constituent as chlorine is bound to be evolved in the form of some compound of lower boiling point than salt. Indeed, is it not possible that a proportion of the large quantities of hydrochloric acid, ammonium chloride, and aluminum chloride evolved during volcanic action may have their origin in this manner? If this speculation were true, it is quite possible that the cyclic sodium, using the term in its widest significance, might exceed the cyclic chlorine, and that the calculations would be still further vitiated.

Without laying too great stress on this speculation, it must not be forgotten that uncertainties of this kind exist, and that the sea-salt method must not be regarded as of greater validity than those founded on pure geology. The method is liable to a number of uncertainties and it would not be wise to lay too great stress on this particular estimate. It is highly probable, however, that this method, when based on more accurate analyses, may act as a check on the results obtained from pure geology, from radioactivity, and from other lines of attack. Nor must it be forgotten that this method,[1] even if in the future it should be superseded, was the first serious attempt to get outside the vicious circle of the classical physical three methods, which have proved such a barrier to the progress of geologic thought on this fascinating cosmic problem.

[1] In making this statement, the interesting investigations of Mr. Mellard Reade on the evolution of carbonate of lime must not be forgotten. This may ultimately prove of greater value than the sea-salt method. Unfortunately, in his later years, this author published other methods, based on less reliable data, which gave a smaller minimum for geologic time. His most valuable work was thus forgotten.

Reviews

RECENT SEISMOLOGICAL LITERATURE

Emilio Böse. "Los temblores de Zanatepec, Oaxaca, a fines de septiembre de 1902" (The Earthquakes of Zanatepec, Oaxaca, at the end of September in 1902), *Paragones del Institute Geológico de Mexico*, Vol. I, No. 1, 1903, pp. 1–19; pls. 1, 2.

Emilio Böse. "A. Villafaña y Garcia y Garcia, El temblor del 14 de abril de 1907" (The Earthquake of April 14, 1907), *ibid.*, Vol. II, Nos. 4–6, pp. 135–258; 43 pls. and a table.

José G. Aguilera (Director). "Catalogo de los temblores (Macroseismos) sentidos en la Republica Mexicana durante los años de 1904 a 1908" (Catalogue of the Earthquakes—Macroseisms—Felt in the Mexican Republic during the Years 1904–8), *ibid.*, Vol. II, No. 10, pp. 389–467.

So soon as the Spanish-speaking peoples appreciate their opportunity in the direction of the investigation of earthquakes, it will be necessary for them to print the results of their researches in one of the better-known languages of sciences, or students of seismology must take up seriously the study of the Spanish language. Between northern Mexico and the southern extremity of the Andean System, is included one of the greatest earthquake provinces of the globe. The recent establishment by the Republic of Chili of a well-equipped seismological service, and the initiation by the Mexican government of an important serial publication largely devoted to earthquakes, may indicate that this time is not far distant. The new serial is issued by the Mexican Department of the Interior and apparently is a continuation under a new name and with slightly altered purpose of the *Anales del Secretaria de Fomento*, etc.

The report upon the Guerrero earthquake of 1897 is a valuable paper of 123 pages, 3 maps, 2 diagrams, and 38 halftone views showing ruined structures and broken ground within the area affected by the earthquake. The text treats in considerable detail of the topography and geology of the district, of the effects of the earthquake, of the character of the motion, and of the "foreshocks" and "aftershocks." Of very special value is a

list of the earlier earthquakes within the province, beginning with 1784. Seven pages are devoted to a list of data from instruments at foreign stations, and fifteen pages to a discussion (largely mathematical) of the depth of the earthquake centrum.

Seismologists will welcome the elaborate catalogue of Mexican earthquakes which is published in the last number of the series, with its earnest of further work along the same line.

Harry Fielding Reid. "Seismological Notes," *Proc. Am. Philos. Soc.*, Vol. XLVIII, No. 192, 1909, pp. 303–12.

Under this somewhat unimpressive title Professor Reid has put forward an entirely new theory of the cause of earthquakes. In his own summary this theory is thus stated:

> Tectonic earthquakes are caused by the gradual relative displacement of neighboring regions which sets up elastic strains so great that the rock is ruptured: and that at the same time of the rupture no displacements of large areas take place, but there occurs merely an elastic rebound, to an unstrained position, of the lips of the fault extending but a few miles on each side of it.

This theory is visualized for the reader by diagrams representing two short wooden blocks joined by a thick layer of stiff jelly which has been divided by a sharp knife into two equal layers. The blocks being held together under slight pressure, they are given a shearing motion. The jelly is thereby deformed much as would be a rubber layer, and the friction between the jelly surfaces is reduced by a release of the pressure upon the blocks. The two jelly layers now suddenly resume their former unstrained attitudes with the production of a fault of lateral displacement at their plane of junction. This fault is supposed to simulate in its manner of formation the recent displacement along the California rift, and the theory will command attention, particularly, since Professor Reid, as a member of the California State Earthquake Commission, has been intrusted with the problems of mechanics involved in the recent earthquake displacements, and has in preparation the second volume of the report of the commission.

The value of the theory will be adjudged differently by different workers, but it seems safe to say that its assumptions are far too sweeping and that the theory in its present form would never have been devised had the study of any save the California earthquake led to its framing. Of all known earthquakes which have been accompanied by visible displacements in the surface of the ground, this one is unique by reason of the large

proportion of the lateral to the vertical component of movement. As already pointed out by several foreign critics, the report of the commission is decidedly provincial in that it fails to take any account of work already done upon earthquakes, and because all conclusions seem to have been reached as though no other earthquake had been known or studied. Probably the most distinguished geologist of the commission has said of the California quake: "That event was so far unforeseen that no seismologists were at hand and the duty of investigation fell, in the emergency, on a volunteer corps of geologists and astronomers" (*Science*, N. S., Vol. XXIX, January 22, 1909, p. 122). While no doubt accounting for the notably local aspect of the study, this hardly furnishes its excuse. The literature of the subject is large and for the most part easily accessible.

In his discussion in support of the theory advanced, Professor Reid says, "there is a consideration which seems almost decisive in its favor." This consideration is derived from trigonometric surveys made (I) 1851–65, (II) 1874–92, and (III) 1906–7 (after the great quake). These surveys show clearly that lateral displacements measured in feet occurred within the wide zone bounding the great rift and in both the intervals I–II and II–III. This result, it should be stated, is quite in harmony with modern views of earth displacments. What is needed, however, in order to prove Professor Reid's contention, is a determined lack of connection in time between displacements during much shorter intervals and the earthquakes which have been so frequent in the district. The crucial question to be decided is whether a movement of a portion of the earth's outer shell was true warping or was a displacement of individual parts *per saltum* by repeated small amounts. Reid's theory leaves the smaller and frequent *temblors* altogether unaccounted for.

The argument that the amplitudes of the displacements revealed in the trigonometric data are greatest in the vicinity of the rift and fall away rapidly from it, is without force, since we know that faults revealed in geological sections quite generally show distribution of displacement over a number of planes within a zone, and the trigonometric stations are here so widely separated as to furnish no crucial data. There is, however, one consideration quite out of harmony with the Reid theory. Rock slabs which, by slow and continued application of stresses, have been forced into warped surfaces have been found to take on a permanent "set" and do not return by rebound to their original attitudes. As already pointed out, the validity of the theory can be tested observationally through the frequent "location" of monuments in earthquake countries and comparison of the results with an accurate catalogue of local earthquakes.

SIEGMUND SZIRTES. "Seismogramme des japanischen Erdbebens am 21. Januar 1906," *Veröffentl. des Zentralbureaus der intern. Seismolog. Assoz.*, Serie A, Abhandl., Strassburg, 1909, pp. 1–50; 2 maps and 7 pls. of seismograms.

SIEGMUND SZIRTES. "Unifilares Horizontalpendel," *ibid.*, 1909, pp. 1–21; 2 pls.

C. MAINKA. "Eine neue seismische Untersuchungsplatte" (Teil I), *ibid.*, 1909, pp. 1–37; 3 pls.

SEIGMUND SZIRTES. "Katalog der im Jahre 1905, registrierten seismischen Störungen" (I Teil), *ibid.*, Kataloge, 1909, pp. 1–193; 1 map.

ADOLF CHRISTENSEN ET GEORG ZIEMENDORFF. "Les tremblements de terre ressentis pendant l'année 1905, *ibid.*, 1909," pp. 1–543; 21 text-maps and a world-map.

The above-listed publications issued from the Central Bureau of the International Seismological Association show what is being accomplished with the funds subscribed by the different contributing governments. The world-catalogue of earthquakes is alone a stupendous undertaking sure to furnish future seismologists with the data for broad and safe generalizations. The bulky volume covering the year 1905 is in two parts, one chronological in its arrangement, while in the other the earthquakes are arranged chronologically under each of twenty more or less arbitrarily chosen earthquake provinces. The maps which show the distribution of the quakes of 1905 are of especial interest and value.

One of the memoirs discusses a new seismograph of fairly simple construction which has been devised by Dr. Szirtes with the purpose of obviating defects which an extensive comparative study has shown to be common to many of the types now in use. Dr. Mainka's "New Seismic Testing Plate" is intended for use in testing seismographic apparatus of a wide range of design. Incidently, it may be mentioned, the plates of the paper give much the best representations of the Mainka Bifilar Conical Pendulum (a form now widely introduced in Germany) that have thus far appeared. Szirtes' monograph on the Japanese earthquake of January 21, 1906, differs widely from the ordinary earthquake report, in that an attempt has been made to bring the instrumental data into some relation to topography and geology. A graded intensity map of Japan shows a somewhat remarkable resemblance to the interesting geognostic map of Japan by the late Baron v. Richthofen. As a result of his study, Szirtes states the

following propositions concerning the propagation of the seismic energy of the earthquake:

1. The propagation is most rapid in the direction of the strike of the rock layers, and slowest perpendicular thereto.

2. Breaks (*Brüche*) in the earth's shell oppose to the propagation a very considerable obstacle.

It appears that the great rift of the *fossa magna*, first made known by Naumann, has played an important rôle in the seismic history of Japan.

F. Omori. "Report of the Observation of Pulsatory Oscillations in Japan" (1st paper), *Bull. Imp. Earthq. Invest. Comm.*, Vol. III, No. 1, 1909, pp. 1–35; pls. 1–6.

This study, though carried out in Japan, was made in consequence of the resolution adopted at the 1907 conference of the International Seismological Association, and had for its object the observation of pulsatory movements on isolated islands and the comparison of the motions observed at several stations within a small area. Dr. Omori has found that these pulsatory motions of seismographs, as regards their periods of vibration, are practically the same all over the earth, and that they are probably due to the translatory movements and not to the inclination of the ground. There are found to be two mean periods of vibration: a short one, $Q_1=4.4$ seconds, and a longer one, $Q_2=8.0$ seconds. The movements occur very frequently, in fact almost constantly, on broad alluvial plains, though but rarely in places situated on granite or Paleozoic rocks. Though up to the present, they have generally been registered on instruments which record horizontal components only, they are found to have a vertical component as well. Marked pulsatory oscillations are connected with the approach of an area of low barometer, these movements being especially those of the shorter period.

W. H. H.

The Metallurgy of the Common Metals, Gold, Silver, Iron, Copper, Lead, and Zinc. By Leonard S. Austin. Pp. 494, $4.00.

In the second edition of this work much of the material has been recast and numerous text figures have been added, with about 100 pages of descriptive matter. This edition contains a comprehensive index, the lack of which was a serious omission to the first edition. The description of the cyanide process has been greatly amplified and much data relating to recent improvements in the practice are included. The metallurgy of zinc, the

methods of refining zinc and lead, and the manufacture of wrought iron and steel are fully treated. The writer's style is clear, concise, and entertaining. For a text introducing the subject to the student or to the mining geologist it is the best work which has come before the reviewer's notice. Its usefulness would be greatly increased, however, if it contained a bibliography. W. H. E.

Elements of Mineralogy, Crystallography and Blowpipe Analysis from a Practical Standpoint. Including a Description of All Common or Useful Minerals, the Tests Necessary for Their Identification, the Recognition and Measurement of Their Crystals, and a Concise Statement of Their Uses in the Arts. By ALFRED J. MOSES, E.M., PH.D., Professor of Mineralogy, Columbia University, New York City, AND CHARLES LATHROP PARSONS, B.S., Professor of General and Analytical Chemistry, New Hampshire College, Durham, N. H. 4th ed. Pp. 448 and 583 figures. New York: D. Van Nostrand Company, 1909. $2.50.

In the fourth edition of this useful work some of the material has been rearranged and the statistical data revised. The tables, with some additions, are essentially as in the previous editions. The book now includes an elementary course in crystallography in which the study of the photographs of actual crystals is utilized with the drawings of geometrical models of crystal. The course in blowpipe analysis and the tables placed at the end of the book are concise and reasonably comprehensive. The section on descriptive mineralogy includes much valuable data on the occurrence, origin, and uses of minerals. W. H. E.

Geology of Morgan County. By C. F. MARBUT. Missouri Bureau of Geology and Mines. Vol. VII, 2d series.

This county lies in southwestern Missouri, on the edge of the Ozark uplift. The chief rocks of the county are cherty, magnesian limestones, with thin bands of sandstone, Cambrian to Mississippian in age, with some Pennsylvanian shales and sandstones locally preserved. Fossils are not abundant and none have been described in this report. Lead, zinc, iron, barite, clay, and coal occur, and have been mined, but only the last three are mined at present. E. R. L.

Biennial Report of the State Geologist, Missouri Bureau of Geology and Mines.

The part of this report of general interest is the last chapter, a report on the mineral resources of the state. The value of the total output in 1907 is estimated at over $41,000,000, of which lead and zinc make up over $18,000,000. This is the largest in the history of the state. The growth of the output has been steady, and will doubtless continue. E. R. L.

The Geology of Pike County. By R. R. ROWLEY. Missouri Bureau of Geology and Mines. Vol. VIII, 2d series.

Pike County is located in the eastern part of Missouri, bordering the Mississippi River. It is essentially a region of hills, streams, and valleys in the eastern part, with more or less level prairie plateau in the west. The rocks consist of alternating limestones and shales, Ordovician to Pennsylvanian in age. They are practically horizontal and are, as a rule, highly fossiliferous. A number of species are described and figured, especially the fauna of the Louisiana (Lower Mississippian) limestone and the tribolites from the Ordovician. A short résumé would add greatly to the value of the report. E. R. L.

Report of Topographic and Geologic Survey Commission of Pennsylvania, 1906–1908.

The work of this commission is done in co-operation with the United States Geological Survey and the results published by the National Survey. The greater part of the present report is under the heading "Appendix E, Report of Progress of Co-operative Geological Survey." Of this the first part is a summary of geological work done in Pennsylvania and a review of the general geology of the state. Then follows a more detailed study of the southwestern part of the state. Except a small dike of peridotite which is reported from one of the mines near Masontown, Fayette Co., the rocks are all Paleozoic sedimentaries, Ordovician to Permian, with a covering of glacial and glacio-fluvial deposits in the southern part of the district.

Special attention is given to the economic resources, of which coal is by far the most important. Pennsylvania produces more coal than any other state or country in the world excepting Great Britain. In 1907 the coal mined was valued at nearly $320,000,000, over half of which was anthracite. Petroleum and gas, clay, and limestone products are also of great importance. E. R. L.

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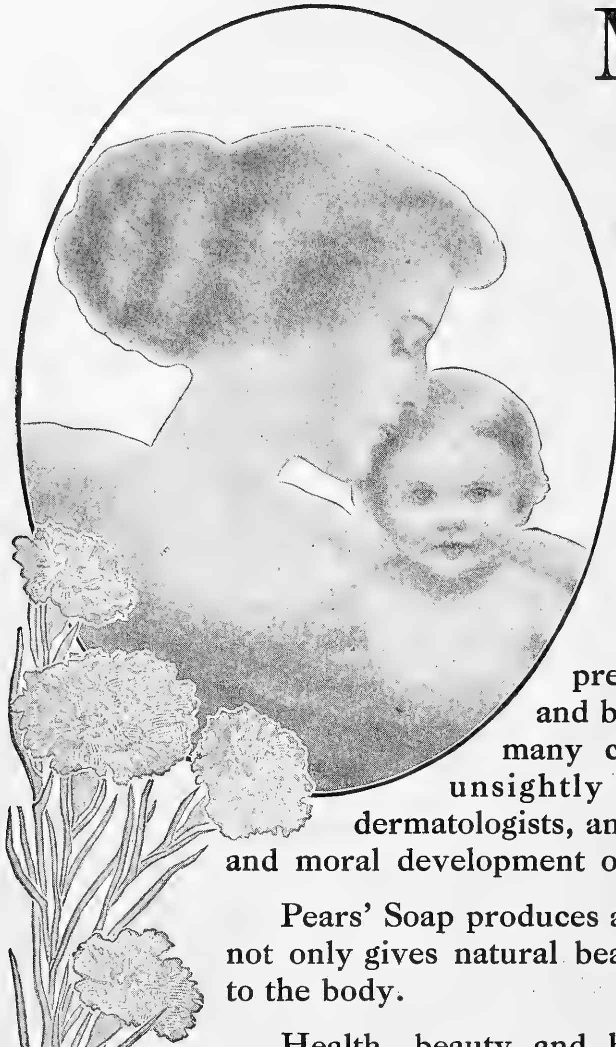

Mother's Day

is every day while the mother lives, and as long afterwards as her children survive her.

For over one hundred years, we have endeavored to help the mother inculcate cleanly habits to produce a healthy skin.

The use of Pears' Soap prevents the irritability, redness and blotchy appearance from which many children suffer, and prevents unsightly disease which so baffles dermatologists, and hinders the proper physical and moral development of the child.

Pears' Soap produces a matchless complexion which not only gives natural beauty but a matchless comfort to the body.

Health, beauty and happiness follow the use of Pears' Soap. The mothers of today can well follow the example of the last six generations and have their memory revered by teaching their children to use

Pears' Soap

Mother's Day is to be observed all over the United States, the second Sunday in May, to honor and uplift motherhood, and to give comfort and happiness to the best mother who ever lived—*your mother.* In loving remembrance of your mother, do some distinct act of kindness—either by visit or letter. A white flower (perfectly white carnation) is the emblem to be worn by you. Send one to the sick or unfortunate in homes, hospitals or prisons.

OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

THE

JOURNAL OF GEOLOGY

APRIL–MAY, 1910

CORRELATION OF THE CENOZOIC THROUGH ITS MAMMALIAN LIFE

HENRY FAIRFIELD OSBORN
American Museum of Natural History, New York City

XIII[1]

The sea borders of the United States may be correlated with each other and with those of Eurasia in Cenozoic times through their invertebrate life, but for the vast interior of the American continent we must depend chiefly upon the mammals and in a less degree upon the reptiles, fishes, insects, and plants. I foresee great aid through these latter sources, but it is clear that the mammals will always afford the chief means of correlation, since in all parts of Europe mammal-bearing formations alternate with marine shell-bearing formations.

The standard divisions of Cenozoic geologic time will always be those established in Europe. The problem set before the paleontologists of our country is therefore to compare and establish our time divisions as closely as possible with the European standards. For this reason since 1899 I have been pursuing an exact investigation of the sequence of mammalian life in America and in the European Tertiary formations, and have enlisted the co-operation of many European and American paleontologists in the hope that such precise

[1] This article, which should have appeared as No. XIII in the series of correlation papers published last year, did not reach the *Journal of Geology* in time to be published in its proper place, in No. 7, 1909.

data may be obtained as to secure common understanding and usage of chronologic terms in the two countries.

Previous to 1898 scattered attempts at the correlation of European horizons *inter se* were made by Dawkins, Schlosser, Osborn, Depéret, and others, but it was not until June, 1905, that there began in the *Comptes rendus* a remarkable series of papers by Depéret entitled "L'évolution des mammifères tertiaires," covering with fulness the whole subject of the succession of mammalian life in Europe, the correlation of all the known horizons, with theories as to the migrations between the continents of Eurasia, North America, and Africa. I am not in accord with Depéret on many of these theories but I accept in full his correlation of the mammal-bearing horizons on the continent, together with his subdivisions of geologic time.

Similarly in America there are the pioneer correlations of Leidy of the American formations with each other and with those of Europe, followed with increasing precision by those of Cope, Marsh, Scott, Clarke, Dall, and Osborn. In 1899 Matthew published *A Provisional Classification of the Freshwater Tertiary of the West,* and this together with his *Faunal Lists of the Tertiary Mammalia of the West,* published in 1909, afforded the American bases for Osborn's *Cenozoic Mammal Horizons of Western North America,* published in 1909, in which for the first time the succession of the mammalian life of the New and Old Worlds is closely compared.

In the meantime increasingly accurate field methods, especially in the horizontal recording of levels after methods introduced by Osborn, Hatcher, and Wortman, have resulted in the subdivision of the old "formations" of Leidy, Cope, and Marsh into successive *Life-zones* similar to those long in use in invertebrate paleontology. These life-zones are obviously as important in questions of time as they are in questions of phylogeny or descent; they narrow down the old correlation standard of the comparison of similar specific and generic stages to different levels; they add greatly to the possibilities of precise comparison in respect to the newer data of correlation, such as detailed evolution of related forms, the simultaneous introduction of new forms by migration, the predominance or abundance of certain forms, the convergence and divergence of American and European faunas.

Putting together all these facts of various kinds, the first result is the proof that the mammalian life of Eurasia and America in Tertiary times passed through a series of grand phases of union, of divergence, of reunion, and perhaps again of divergence. There are seven of these phases.

In the *first*, in Basal Eocene times, we find North America, Europe, and possibly South America peopled with archaic mammals of Mesozoic ancestry.

In the *second* faunal phase, of Lower Eocene times, we observe the first modernization, which occurs simultaneously in Europe and North America, by the invasion of many modern families of mammals, which intermingled with the archaic; the life of Europe and North America continues to be very similar.

In the *third* faunal phase, beginning in Middle Eocene times, the mammals of America and Europe gradually diverge and undergo an independent evolution with little or no faunal interchange; at the close of the Eocene the two faunas are very far apart.

In the *fourth* faunal phase, beginning in Lower Oligocene times, there is a sudden reunion of New and Old World life. At the same time there occurs in both countries a second very surprising modernization apparently by the further invasion of modern forms from the north.

A *fifth* faunal phase occurs in the Middle Miocene, when there is a fresh reunion in the New and Old Worlds by the arrival in America of the proboscideans and the short-limbed rhinoceroses.

Then follows a long period of independent evolution in the two countries until in the Middle Pliocene we enter a *sixth* faunal phase, in which a close land connection with South America is re-established, after an interval of separation reaching back into Eocene times.

Finally a *seventh* faunal phase occurs in Pleistocene or Glacial times, when all the larger North American mammals become extinct, as well as the south American invading stocks, while North America is replenished by a large fauna from Eurasia.

It will be noticed that these phases are in no way coincident either with the greater or with the lesser time divisions, for the obvious reason that these time divisions have all been established on the basis of the evolution of invertebrate life in Europe.

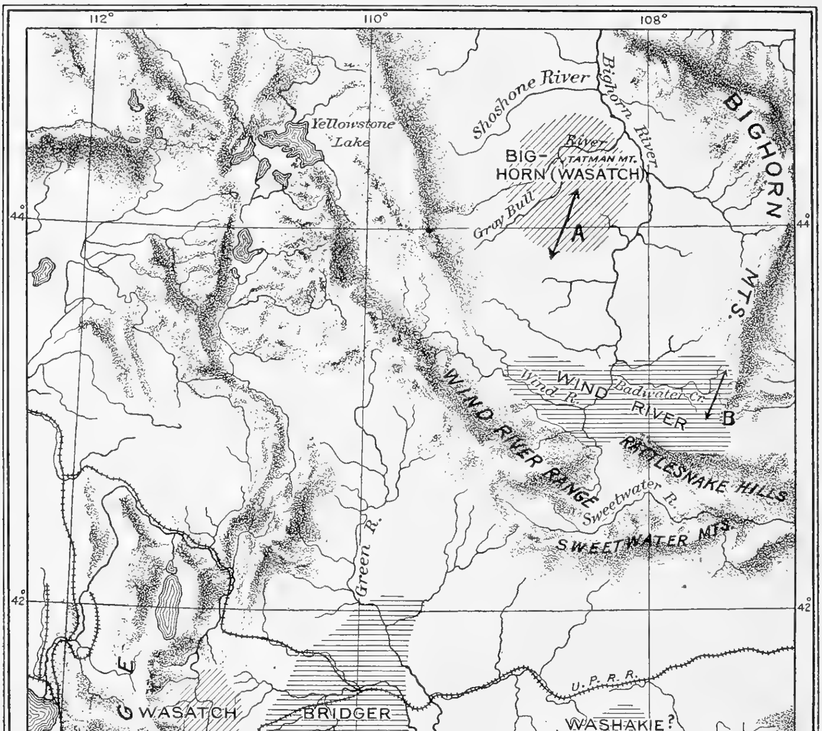

FIG. 1.—Map of southwestern Wyoming and northern Utah, showing partial areas of the Wasatch, Wind River, Bridger, and Uinta formations. Extensive areas of the Wasatch are purposely omitted. A, B, lines of sections by F. B. Loomis.

EOCENE

Basal.—The very opening of the Eocene furnishes one of the most brilliant examples of the possibilities of precise correlation through vertebrate life. Changes occurring in the interior of the American continent may be compared precisely with those along the northern coasts of France and Belgium. In each case great forms of reptilian life persist to the very close of the Cretaceous; the conditions of the American "Laramie," "Hell Creek," or Ceratops beds are similar to those of the Danian or Maestrichtian of Belgium; both mark the abrupt termination of the Age of Reptiles; both are overlaid by beds containing a number of very distinctive types of archaic mammals mingled with those of distinctive reptiles (*Champsosaurus*) found alike in the Puerco of Mexico, the Fort Union of Montana, the Thanetian of northern France. Thus we believe the opening of the Tertiary admits of close correlation in the Old and New Worlds. The succeeding rich Puerco-Torrejon mammalian life of New Mexico, so far as known, parallels that of the Thanetian (including the Cernaysian) stage of northwestern Europe. It is all *Paleocene*, or Basal Eocene.

Lower.—The beginning of the Lower Eocene is clearly defined in the Rocky Mountain region and with equal sharpness in northern France and Belgium by the appearance of *Coryphodon*, and by the opening of the second faunal phase with its advent of modernized life. Our Lower and Upper Wasatch correspond respectively with the Sparnacian and Ypresian stages of France. It is represented in deep and fairly rich exposures in northern New Mexico and in western, central, and northern Wyoming.

The Wind River of central Wyoming together with the Lower Huerfano near the Spanish Peaks of Colorado marks the upper life-zone of *Coryphodon* and may prove to correspond closely with the Ypresian of France. In the Rocky Mountains the Wind River is readily distinguished by the survival of a number of characteristic Lower Eocene types (*Coryphodon*, *Phenacodus*) and the fresh arrival of a number of equally characteristic Middle Eocene types (uintatheres, titanotheres). It is consequently an ideal transition fauna. Unfortunately the formations believed to be of corresponding age in France are poor in mammal remains.

From this time on to the summit of the Eocene we are passing into the third faunal phase, or divergence and independent evolution of the life of Europe and America. Consequently close correlation is

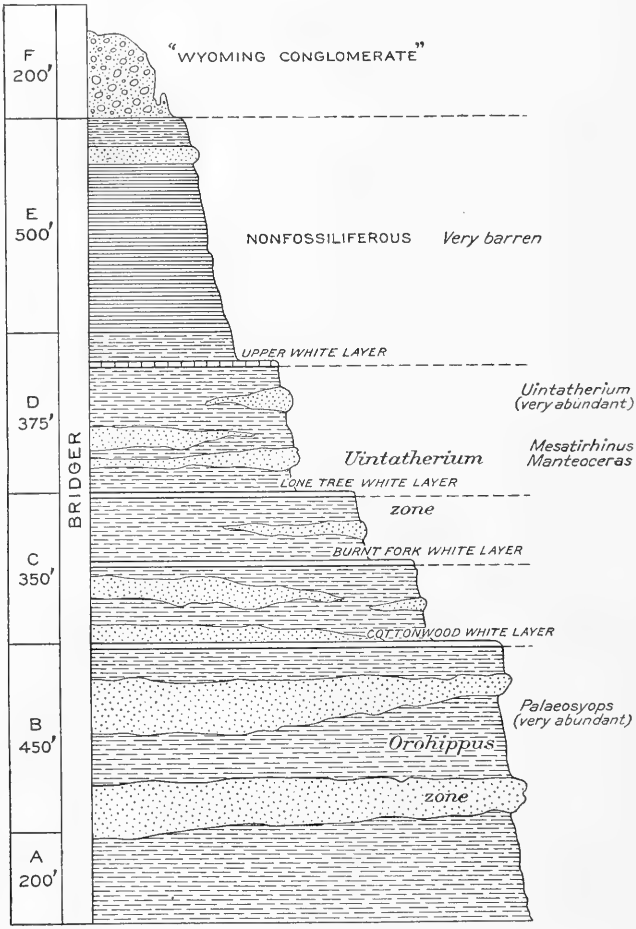

FIG. 2.—Columnar section of the Bridger formation, Henrys Fork, western Wyoming. After studies by Matthew and Granger, 1902.

almost impossible; at no period in the Tertiary were the Nearctic and Palearctic faunas so widely separated.

Middle.—With the American Bridger, 1,800 feet in thickness, we enter the Middle Eocene and broadly compare the Lower Bridger

with the Lutetian and the Upper Bridger with the Bartonian of France. The precise survey of the life-zones of the Bridger by Granger and Matthew marks one of the greatest advances of recent times.

Similarly under the direction of the present writer the Washakie

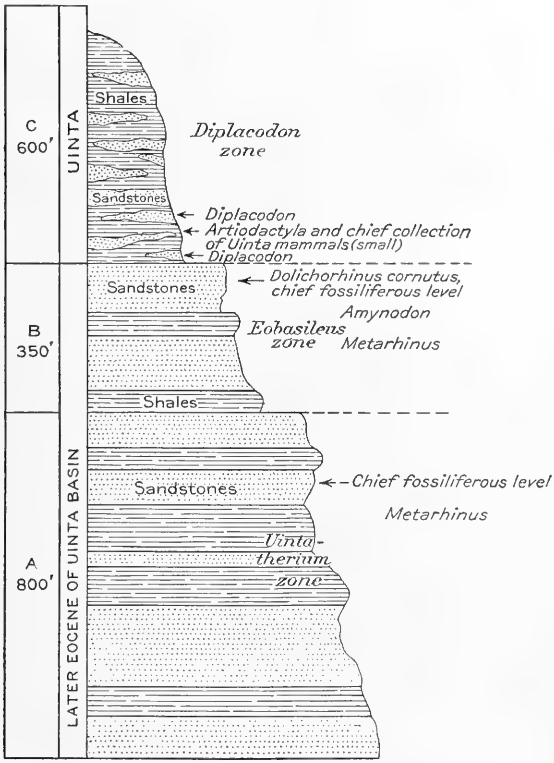

FIG. 3.—Columnar section of the Uinta formation, northern Utah. In A and B the diagram does not properly represent the irregular nature of the so-called sandstones and clays, which are probably in part coarser and finer volcanic-dust deposits. Modified from notes by O. A. Peterson, 1894. Faunistic studies of Osborn.

of central Wyoming has been surveyed precisely by Granger, proving that the Lower Washakie is identical in age and in its mammalian life with the Upper Bridger and broadly corresponds with the Bartonian, or closing stage of the Middle Eocene of France. We are now in the Uintatherium Zone, all the famous discoveries of Cope and

Marsh having been made at this level. Here belongs also the beginning of the Uinta deposition of northern Utah.

We now pass into the Eobasileus Zone of the Upper Washakie and the Middle Uinta, in which the long-headed uintatheres described by Cope as *Eobasileus* and *Loxolophodon* occur mingled with remains of highly specialized Eocene titanotheres. This is apparently the lower level of the Upper Eocene and is broadly comparable with the Ludian stage of France.

Upper.—The succeeding Ligurian stage of France may be paralleled with the upper, or true Uinta, the Diplacodon Zone of Marsh. The zonal type is a large titanothere with well-developed bony horns, transitional in many characters to the Lower Oligocene titanotheres; in fact, the summit of the thick Diplacodon Zone of 600 feet will probably prove to coincide with the base of the White River Group on the great plains. Quite recently, during the summer of 1909, the much-desired sequence of Oligocence and Eocene strata was discovered by Mr. Granger of the American Museum expedition. The Diplacodon Zone has been discovered in the Wind River region of Wyoming underlying the Titanotherium Zone.

The Ligurian stage of France is that of the famous Gypse de Montmartre discovered by Cuvier, full of paleotheres and anoplotheres, a mammal fauna totally distinct from that of the Rocky Mountain region.

OLIGOCENE

Lower.—The Oligocene opens in the New and Old Worlds with the fourth faunal phase and second modernization, which since it affects alike Europe and America probably indicates a fresh migration from the great unknown northern, or Holarctic region. With this migration close faunal resemblance is re-established with western Europe, and thereby comes a welcome means of geologic correlation; in other words, we may with considerable confidence consider that the base of the White River group was nearly coincident with the inferior Tongrian of France. Sixteen new families of mammals appear in America, all of them still existing, and seventeen modern, or still existing, families appear in Europe. This momentous faunal change in North America is partly attributable to the fact that this is our first glimpse of the life of the Great Plains.

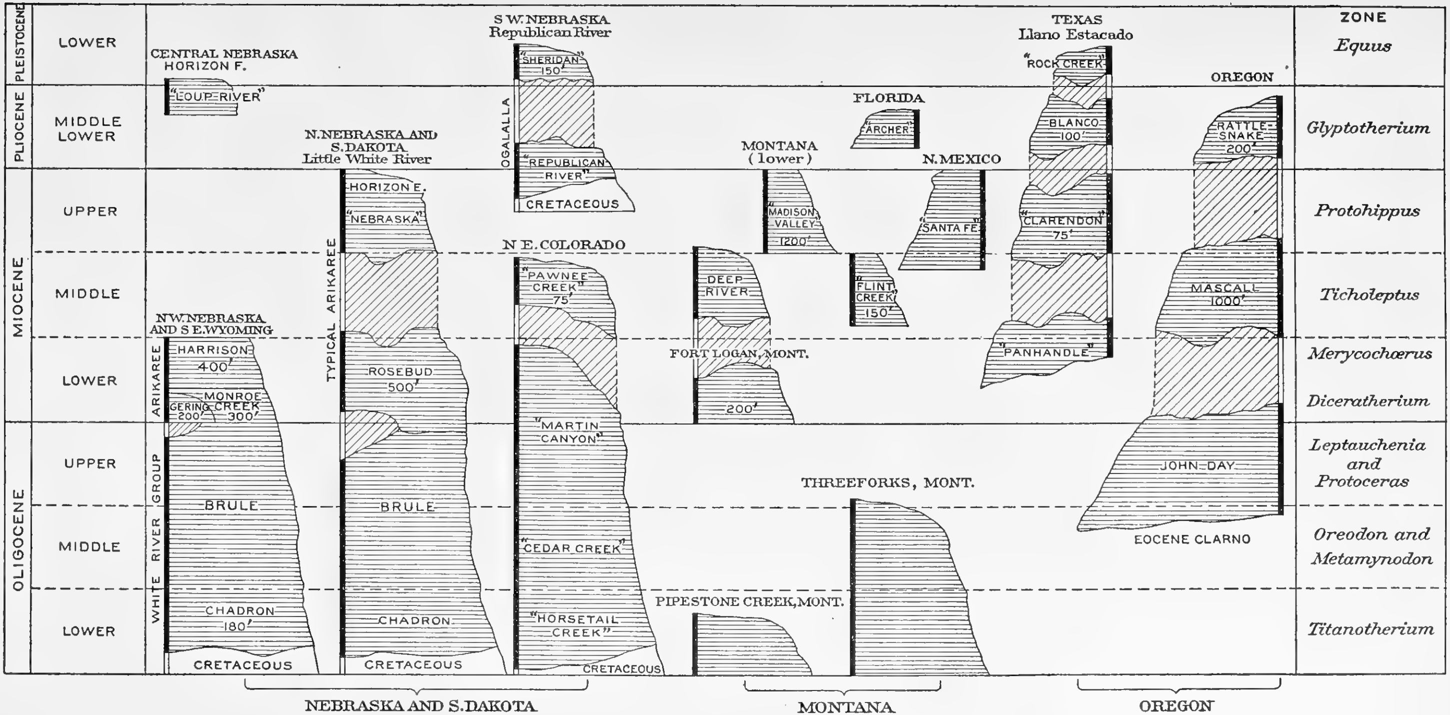

FIG. 4.—Provisional correlation of some of the chief epicontinental Oligocene-Pleistocene deposits and formations of the West in which fossil mammals have been recorded. Unlike the sections in the other figures, these sections are not represented to scale; they are purely conventional. After W. D. Matthew and H. F. Osborn, 1907.

Middle.—The Lower Oligocene, or Titanotherium Zone, most accurately surveyed by Hatcher, is succeeded by the Middle Oligocene or Oreodon Zone, broadly comparable with the Superior Tongrian and Stampian of France, both containing similar types of amphibious rhinoceroses and many other mammals. One of the chief points of interest here is the sharp separation discovered by Matthew between the plains-living mammals buried in the so-called clays, or finer deposits, and the forest-living mammals buried in the coarser intrusive river sandstones.

Upper.—The close of the Oligocene takes us into the John Day tuff deposits of Oregon, and is generally parallel with the Aquitanian Stage of France, typified by St. Gérand-le-Puy. It is the Diceratherium Zone, or the climax of the evolution of the pair-horned rhinoceroses in both countries. We pass also into the Upper Merycochoerus Zone at the summit of the John Day and at the base of the Arikaree formation extending along Pine Ridge of South Dakota. Here we are again in difficulty in determining just when the American Oligocene should be regarded as closing and the Miocene as beginning. An abundance of diceratheres and entelodonts still betokens Oligocene times, but it is possible that we may be in the Miocene. This is one of the doubtful points requiring further investigation.

MIOCENE

The solution of the Lower and Middle Miocene sequence in America through the discoveries of Hatcher, Peterson, and of Matthew marks another great advance of recent years.

Lower.—There is no question that in the Upper Arikaree, the Upper Harrison of Hatcher, and the Upper Rosebud of Matthew we are fairly in Lower Miocene times corresponding with the Burdigalian of Europe. There is now considerable faunal difference between the New and Old Worlds. The Proboscidea certainly enter Europe at this time, and one of the debated points is when they first appear in North America.

Middle.—The Vindobonian, or Middle Miocene of Europe, divided into the three successive stages of Sansan, Simorre, and St. Gaudens, is again with considerable confidence compared with the Deep River of Montana, and the Pawnee Buttes of Colorado, through

the researches of Scott and Matthew. Here we enter the fifth faunal phase, marked by fresh migrations and the first undoubted appearance of the proboscideans and short-limbed rhinoceroses in America, both arrivals from the Old World. Physiographic changes are indicated in evidence of increasing summer droughts, numerical increase of animals adapted to plains-living and the semi-arid conditions, in the disappearance of most of the browsing types. The correlation is, however, by no means close at present, because the life of Europe and the great American plains is of different local habitat.

Upper.—In the Upper Miocene, however, we are again somewhat more confident in correlating our Hipparion and Procamelus Zone, the "Loup Fork" of early writers, with the Pontian or Pikermi stage of Europe typified by the wonderful advent of the plains fauna of Asia which spreads all over southern Europe, probably into Africa and the far East of southern Asia and China.

PLIOCENE

It is difficult again to demarkate the close of our Miocene and the beginning of our Pliocene. For the first time in American Tertiary history an invertebrate paleontologist (Dall) comes to our aid through discovering that the mammals of the Alachua Clays of Florida overlie certain true Lower Pliocene molluscs. The mammals of these clays are comparable to those of the Republican River of Kansas, and we are consequently disposed to place the latter in the Lower Pliocene. It is at least a more recent phase than the "Loup Fork," and is hence distinguished as the Peraceras Zone, from the presence of a number of broad-skulled hornless rhinoceroses.

Lower.—Of undoubted Lower Pliocene age is the recently discovered Snake River deposit of western Nebraska, the Neotragocerus Zone, and the Virgin Valley and Thousand Creek of Nevada. The arrival at this time of true Old World tragocerine and hippotragine antelopes from Asia, as identified by Matthew and Merriam, is one of the most noteworthy discoveries in recent paleontology. These antelopes may prove to demarkate our Lower Pliocene, in which case the Republican River will be pushed back into the close of th Miocene because it certainly does not contain these Old World forms.

The Lower Pliocene, or Plaisancian, of Europe is represented by

PRELIMINARY CORRELATION

		EUROPE	ASIA	NORTH AMERICA
PLIOCENE	Upper	Sicilian	Siwaliks	"Loup River"
	Middle	Astian	Siwaliks	Blanco
	Lower	Plaisancian	Siwaliks	Thousand Creek Rattlesnake and Republican River
MIOCENE	Upper	Pontian	Manchhar	"Loup Fork" Madison Valley Clarendon
	Middle	Vindobonian	Manchhar	Deep River Pawnee Buttes Mascall
	Lower	Burdigalian		Arikaree "Upper Harrison" Rosebud
			AFRICA	
OLIGOCENE	Upper	Aquitanian		Harrison (Lower) John Day White River(Upper)
	Middle	Stampian		White River (Middle) Brulé Clays
	Lower	Sannoisian	Fayûm	White River (Base) Cypress Hills Pipestone Creek Chadron
EOCENE	Upper	Ludian	Fayûm	Uinta (Upper and Middle) Washakie (Upper)
	Middle	Bartonian		Uinta (Lower) Washakie (Lower) Bridger (Upper)
		Lutetian		Bridger (Lower) Huerfano (Upper)
		Upper Ypresian		Bridger (Lower) Huerfano (Upper) Green River
	Lower	Lower Ypresian		Huerfano (Lower) Wind River Wasatch (Upper)
		Sparnacian (Upper Landenian of Belgium)		Wasatch (Lower)
		Upper Thanetian (=Cernaysian) (Lower Landenian of Belgium)		Torrejon Fort Union
	Basal	Lower Thanetian		Puerco Fort Union
CRETACEOUS	Uppermost	Danian = Maestrichtian (Terrestrial) (Marine)		Hell Creek

the mammalian life of Casino, which is very sharply demarkated from that of Pikermi.

Middle.—The Astian, or Middle Pliocene, life of France, typified at Roussillon and Montpellier, is broadly comparable with the Blanco of Texas, where we enter the sixth faunal phase, marked by the invasion of South American armored edentates, or glyptodonts, into the southern United States. These deposits are accordingly known as the Glyptotherium Zone. They mark a great advance upon those of the Republican River.

Upper.—The Upper Pliocene, or Sicilian, stage of Europe, typified by the Val d'Arno fauna of northern Italy, is hardly comparable with any American horizon. We are here on the border-line between Pliocene and Pleistocene, and a great deal of research is still needed. The Peace Creek deposits of Florida (Dall) may help us because here we discover an Equus and an Elephas Zone overlaid by marine Upper Pliocene molluscs. Rather primitive forms of Equus and Elephas are also characteristic new arrivals of the Upper Pliocene, or Sicilian, stage of Europe. The same doubt applies to the little-known "Loup River" of Nebraska, in which *Equus* and *Elephas* were discovered by Leidy many years ago.

PLEISTOCENE

Perhaps the most striking determinations which await the mammalian palaeontologist are those which close comparison of the Pleistocene stages in the New and Old Worlds will afford. In Europe we have four great series of correlation data, namely:

The geologic succession of the glacial depositions;

The faunal succession especially among the higher mammals;

The evolution of stone implements of human manufacture;

Stages in the skeletal evolution of man.

In America the two kinds of data connected with the evolution of man are entirely wanting, and we are thrown back on the geologic and the faunistic divisions; consequently close comparison in these two lines of evidence common to both countries is all the more necessary. In Europe it is possible to distinguish four grand faunistic phases, namely:

The first early Pleistocene fauna, Eolithic Stage of culture;

Second or mid-Pleistocene fauna, Eolithic and early Paleolithic Stages;

Third or Upper Pleistocene fauna, late Paleolithic Stage;

Fourth, post-Glacial fauna, Neolithic Stage.

From close study of the Pleistocene life of North America there is promise of correlation with Europe through identification of American with European glacial and interglacial periods, through the discovery and identification of interglacial faunas, as in the Aftonian and Toronto deposits, through the careful recording of the time of extinction of native types and of the time of arrival of new types to demarkate our Pleistocene also into great successive life-zones.

The chief progress made thus far (1909) is that we begin to recognize the following divisions of American life:

Early and mid-Pleistocene life of the plains, *Equus* Zone;

Mid-Pleistocene life of the forested regions, *Megalonyx* Zone;

Life of the maximum cold period, *Ovibos* Zone;

Life of post-Glacial times, Zones of *Cervus* and *Homo.*

Especially interesting is the coincidence of the maximum cold period, or *Ovibos*, Musk Sheep Zone of America, with the maximum cold period, or *Elephas primigenius, Rangifer tarandus* Zone of Europe.

It is obvious that we should never expect to discover as clear demarkation of the life-zones in America as in Europe because of the vast refuge areas of the mammals in the south. In Europe the glacial advances are sharply punctuated by the appearance and disappearance of species. In America apparently such appearances and disappearances are gradual.

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THE GEOLOGIC RECORD OF CALIFORNIA

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The geologic record of California is exceedingly complete for a single geographic region, because of the two ancient and persistent seas that covered some portion of its surface during each geologic period. These seas were the Pacific Ocean and the Great Basin Sea.

The geologic history of California is given below chiefly in the form of tables, for the sake of brevity, and without a discussion of the faunas and floras of the various formations, since that would extend the paper beyond the size intended. Such a discussion is reserved for a later paper.

The tables here given have been based on a critical study of all the papers on the stratigraphy of California, and on the writer's experience in this field for a period of seventeen years, of which a large part has been spent in field study.

Great Basin Sea.—The older portion of the geologic record, from the Cambrian to the top of the Middle Jurassic, has been preserved chiefly in the sediments of the Great Basin Sea, while during those ages that part of California which was afterward covered by the Pacific Ocean was either above water, or has had its sediments so much metamorphosed that their age is not positively determinable.

The Great Basin Sea of Paleozoic and early Mesozoic time covered approximately the area of the Great Basin of the present age, sometimes more, and sometimes less, dwindling away gradually from the noble expanse of the Carboniferous Sea to the shrunken remnant in early Mesozoic time. This basin at all times was directly connected with the Pacific Ocean, by a broad passage to the northwest; and during a part of the Paleozoic, especially during the period of the Coal Measures, it was joined to the Mississippian Sea. At all other times it was exclusively western, and the marine Triassic and Jurassic history of the United States is its peculiar property. It has played

CENOZOIC

System	Series		Formation		
Quaternary	Pleistocene				Terrace formations
			San Pedro	Los Cerritos beds	
				Deadman Island beds	
					Glacial beds
Tertiary	Pliocene		Merced	Sandstones of Lake Merced with Cardium meekanum and Scutella interlineata	Paso Robles: Santa Clara lake beds
			San Diego	Purisima; Sandstones of San Diego and Half Moon Bay, with Pecten healeyi	Paso Robles: Tulare lake beds
	Miocene	Upper	San Pablo	Sandstones of San Pablo Bay and the Coalinga region, with Pecten pabloensis and Pecten oweni	Upper flora of Mt. Diablo region
		Middle	Santa Margarita	Sandstones of Salinas Valley, with Pecten estrellanus, Ostrea titan, and Tamiosoma gregaria	Auriferous Gravels
			Monterey	Monterey Shales with Pecten discus and Pecten peckhami	Auriferous Gravels
		Lower	Vaqueros	Sandstones of Monterey and San Luis Obispo counties, with Turritella inezana and Mytilus mathewsoni	Auriferous Gravels
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very much the same part in the geologic history of North America as the ancient Mediterranean or Tethys did in the history of Europe, though on a much smaller scale, since it was epicontinental, and not intercontinental. The Cambrian, Silurian, and Devonian sediments of California are mere fragments of little area and thickness, representing only a small part of the entire time of those ages. The Carboniferous, however, is fairly complete, all three major divisions being fully represented by marine faunas. The Triassic period is well represented; the Lower Triassic is nearly as good as the standard American section of Idaho; the Middle Triassic has both of the greater divisions, although the main portion is not nearly so complete as the standard section of the West Humboldt Range in Nevada. The Upper Triassic of California is the standard for this epoch in America, and compares very favorably with the rest of the world in the richness of its faunas, and the completeness of the record. The Jurassic section of the Great Basin Sea is the most complete in the United States, having portions of each stage from Lias to Kelloway, inclusive; but it is fragmentary, the faunas being poorly preserved and scanty. It is not comparable with the Jurassic record of Alaska and British Columbia, and nowhere approaching that of South America. With this epoch the marine column of the Great Basin ends abruptly, as the sea was obliterated at the beginning of the Cordilleran revolution.

Pacific record.—The marine record of California from the bottom of the Upper Jurassic through the Quaternary was kept exclusively by the Pacific Ocean. This was divided between two provinces, or areas of sedimentation, the Sierra Nevada, and the Coast Ranges, but the distribution was not balanced. The Pacific province is one of the great geosynclines, with sediments approximating seventy thousand feet in thickness, and undergoing subsidence more or less continuously, though spasmodically, from the Triassic onward, interrupted by great periods of orogenic activity. This is a part of that grand structural feature of the continent of which the Great Valley, the Gulf of California, the Willamette Valley, and Puget Sound are mere remnants.

The recognizable Paleozoic and early Mesozoic sediments are confined to the Sierra Nevada, while the Cretaceous and Tertiary

GEOLOGIC COLUMN OF CALIFORNIA

Standard Marine Section — Land Equivalent

	System	Series			Standard Marine Section	Land Equivalent
ARCHAEAN					Schists and gneisses of the Sierra Nevada	
PALEOZOIC	Cambrian	Lower		Silver Peak	Limestones of White Mountains with Olenellus, and banks of Archaeocyathus	
	Silurian	Upper	Niagara	Grizzly — Montgomery	Limestone of Plumas County, with Niagara fauna	
	Devonian	Middle		Sacramento — Kennett	Limestones of Kennett, with coral reefs, Favosites canadensis	
	Carboniferous	Mississippian		Bragdon	Bragdon shales of Trinity County	
		Coal Measures		McCloud — Baird	Black siliceous shales of McCloud River, with Productus giganteus, P. burlingtonensis, Orthis michelini	
				McCloud — McCloud Limestone	Gray limestones of McCloud River with Fusulina robusta, F. cylindrica, Clisiophyllum gabbi	
				McCloud — Nosoni	Sandstones and tuffs of Shasta and Plumas counties with Fusulina elongata	
		Permian		Wildwood	Limestones of Trinity County with Guadalupian fauna, Stacheoceras, etc.	
MESOZOIC	Triassic	Lower		Inyo — Meekoceras Beds	Gray limestones of Inyo Mountains with Meekoceras gracilitatis, Pseudosageceras intermontanum, and Ussuria compressa	
				Inyo — Parapopanoceras Beds	Black limestone of Inyo Mountains with Parapopanoceras, Hungarites, and Ptychites	
		Middle		Pitt	Black shales of Pitt River, with Ceratites, Anolcites, and Arcestes	
		Upper		Hosselkus	Shales of Brock Mountain with Halobia rugosa	
				Hosselkus	Limestones of Shasta County with reef corals, Tropites subbullatus, and Halobia superba	
				Brock	Shales with Pseudomonotis subcircularis	
	Jurassic	Lower	Lias	Hardgrave	Arietites beds of Inyo County and Nevada	
				Hardgrave	Sandstones of Taylorsville, Big Bend, with Pecten acutiplicatus	
		Middle	Oolite	Plumas	Mormon sandstone with Oolite fauna	Oroville Flora: Monte de Oro slates of Oroville, with lower Oölite flora, associated with marine Jurassic forms
				Plumas	Hinchman tuff and sandstone of Plumas County, with reef corals	
		Upper	Kimmeridge	Auriferous Slates — Mariposa	Mariposa slates of the Gold Belt with Aucella erringtoni and Cardioceras alternans	
			Portland	Auriferous Slates — Colfax	Tuffs and shales of the Gold Belt with Perisphinctes colfaxi	Oregon Flora: Flora of southern Oregon supposed to be Jurassic, but possibly associated with marine Knoxville forms
	Cretaceous	Lower	Neocomian	Shasta — Knoxville	Lower Knoxville shales with Phylloceras knoxvillense and Aucella piochii	Shasta Flora: Shasta flora associated with Knoxville species
				Shasta — Knoxville	Upper Knoxville shales of Coast Ranges with Aucella crassicollis	
			Gault	Shasta — Horsetown	Horsetown shales of Sacramento Valley with Desmoceras hoffmanni, Phylloceras onoense, Lytoceras batesi	Shasta flora associated with Horsetown species
		Upper	Cenomanian / Danian?	Chico	Lower Chico beds with Schloenbachia, Placenticeras, Phylloceras ramosum	Chico Flora
				Chico	Upper Chico sandstones with Schloenbachia chicoensis and Pachydiscus newberryanus	
CENOZOIC	Tertiary	Eocene	Midway	Martinez	Sandstones of Martinez with Pholadomya nasuta	
			Claiborne	Tejon	Sandstones of Ft. Tejon, Martinez, and Merced Falls with Venericardia planicosta	Ione Formation: Coal beds of Mt. Diablo region with subtropical flora
		Oligocene		Astorian — San Lorenzo	Sandstones and shales of [illegible] Cruz C[illegible]	
		Miocene	Lower	Vaqueros	Sandstones of Monterey and San Luis Obispo counties, with Turritella inezana and Mytilus mathewsoni	Auriferous Gravels
			Middle	Monterey	Monterey Shales with Pecten [illegible] and Pecten peckhami	
			Upper	Santa Margarita	Sandstones of Salinas Valley, with Pecten estrellanus, Ostrea titan, and Tamiosoma gregaria	
		Pliocene		San Pablo	Sandstones of San Pablo Bay and the Coalinga region, with Pecten [illegible] and Pecten oweni	Upper flora of Mt. Diablo region
				San Diego — Purisima	Sandstones of San Diego and Half Moon Bay, with Pecten [illegible]	Paso Robles: Tulare lake beds
				Merced	Sandstones of Lake Merced with Cardium meekianum and Scutella interlineata	Santa Clara lake beds
	Quaternary	Pleistocene		San Pedro	Los Cerritos beds	Glacial beds
				San Pedro	Deadman Island beds	Terrace formations

System — Series — Formation

GEOLOGIC RECORD OF THE GREAT BASIN SEA IN CALIFORNIA

Cenozoic	Quaternary		Lahontan lake beds
Cenozoic	Tertiary		Miocene, Truckee, lake beds
Cenozoic	Tertiary		Eocene, Esmeralda, lake beds
Mesozoic	Jurassic		Cordilleran revolution, uplift and metamorphism of Sierra Nevada and obliteration of the Great Basin Sea
Mesozoic	Jurassic	Middle	Hinchman tuff and sandstone of Plumas County, with Kelloway fauna, and reef-building corals
Mesozoic	Jurassic	Middle	Mormon sandstone and Thompson limestone of Plumas County with lower Oölite fauna
Mesozoic	Jurassic	Lower	Hardgrave sandstone of Plumas County, with Upper Liassic fauna
Mesozoic	Jurassic	Lower	Arietites limestones of Inyo County, California, and West Humboldt Range, Nevada
Mesozoic	Triassic	Upper	Pseudomonotis shales of Shasta and Plumas counties
Mesozoic	Triassic	Upper	Hosselkus limestone of Shasta County, with coral reefs. *Tropites subbullatus* fauna.
Mesozoic	Triassic	Middle	Pitt shales of Shasta. Star Peak limestone of West Humboldt Range, Nevada
Mesozoic	Triassic	Middle	Black limestone of Inyo Range, with Middle Triassic fauna
Mesozoic	Triassic	Lower	Gray limestone of Inyo Range, with Meekoceras fauna
Paleozoic	Carboniferous	Upper	Wildwood limestone of Trinity County, with Permian fauna
Paleozoic	Carboniferous	Upper	Nosoni tuffs and shales of Shasta County, with fauna transitional to Permian
Paleozoic	Carboniferous	Middle	McCloud limestone of Shasta County, with Coal Measures fauna, and coral reefs
Paleozoic	Carboniferous	Lower	Baird shales of Shasta, with Asiatic Subcarboniferous fauna
Paleozoic	Carboniferous	Lower	Bragdon shales of Trinity County, without definite fauna
Paleozoic	Devonian	Middle	Kennett limestones of Shasta County, with coral reefs, *Favosites, Diphyphyllum,* etc.
Paleozoic	Silurian	Niagara	Montgomery limestone of Plumas County, with reef-building corals
Paleozoic	Cambrian	Lower	Olenellus limestone of Inyo County, with reefs of Archaeocyathus
Archaean			Pre-Cambrian schists of Inyo County

strata are most complete in the Coast Ranges. The Sierran record is fragmentary, the formations being incomplete, separated by great unconformities, including great masses of tuffs and igneous rocks, and showing evidence of important recurring orogenic and volcanic activity.

The Coast Range province, too, showed this same phenomenon in its Paleozoic and early Mesozoic sediments, but from the bottom of the Cretaceous to the middle of the Miocene conditions were more uniform, indicating moderately quiet advance and retreat of the sea, with minor unconformities, smaller masses of igneous intrusives, and outpourings of surface lavas. The Coast Range revolution, about the middle of the Miocene epoch, broke the monotony of this history, and for a time there was much mountain-making activity. Minor outpourings of lava occurred along the coast, while farther to the northeast the Columbian lava flood overwhelmed an area of about two hundred thousand square miles, and the rejuvenation of the Sierra Nevada was beginning.

The Cretaceous section of the Coast Ranges is more complete than that of any other single province in America. It lacks only the uppermost portion, and shows a variety of conditions not seen anywhere else, from the boreal faunas of the Knoxville to the tropical faunas of the Horsetown and Chico epochs, with fossil floras interbedded in every formation.

The Tertiary marine section of the Coast Ranges is not only the most complete in America, but also more complete than that of any other single geographic region in the world. Every minor division is fully represented by marine faunas, and most of them have fresh-water beds intercalated, with fossil plants and freshwater animals.

The Quaternary marine section of the Coast Ranges is the most complete that has been described, for this is almost the only known region where there has been much post-Quaternary orogenic activity. In nearly all other regions the Quaternary sediments are still buried under the oceans in which they were deposited.

ROCK-FORMING AGENCIES OF CALIFORNIA

Igneous rocks.—A large part of the surface of the state, a little less than one-half, is made up of igneous rocks. Of these the most

important group consists of deep-seated granitic rocks, granites, grano-diorites, diorites, and gabbros, compounds of feldspars and ferro-magnesian minerals, such as hornblendes, pyroxenes, and mica. The greatest of these batholites is the great igneous mass of the Sierra Nevada, making up the bulk of that mountain chain. Smaller batholites of similar character are in the Sierra Madre Range, the White Mountain Range, the Klamath Mountains, and in the Santa Lucia Mountains.

Associated with the deep-seated granitic rocks in nearly all these regions there are numerous dyke-rocks, similar in chemical nature to the parent masses, but showing only a small surface area.

A second group is composed of basic intrusives, chiefly peridotites, now largely changed to serpentine, rich in olivine and other ferro-magnesian minerals. These cover great stretches in the Coast Ranges, where they are largely of Franciscan age, older than the Cretaceous; they also form less extensive masses in the Sierra Nevada.

A third group is composed of lavas, mostly andesites and basalts, surface flows from volcanoes. These are chiefly of Tertiary age, Middle Miocene, and, together with the less important rhyolite flows, they cover broad areas in northeastern California, and smaller patches in all the other mountain regions of the state. The flows in northeastern California are a part of the Columbian field, and doubtless came from fissure-eruptions. The others came from ordinary volcanoes, though in most cases the volcanic cones are long since destroyed. Mt. Shasta and Lassen Peak are the two grandest volcanoes of the state, the southern extension of the Cascade Range, still preserving their ancient form and some feeble remnants of their old-time activity.

Inorganic sediments.—The greater part of the surface of California, a little more than half, is made up of sediments. These are of two groups, (1) inorganic, and (2) organic.

The inorganic sediments are far greater in thickness and areal extent, sandstones and shales, derived from the decay of crystalline rocks. The quartz and undecomposed feldspars furnished the sand grains, and the decomposed feldspars furnished the clay for the shales. The sandstones of California are remarkable for the large quantity they contain of undecomposed fragments of minerals derived

		MEDITERRANEAN REGION	ORIENTAL REGION	BOREAL REGION	WEST AMERICAN REGION
RECENT			Marine fauna of Japan		Marine fauna of California
QUARTERNARY					
					Warm water marine fauna of Calif.
			Cold water marine fauna of Japan		Cold water marine fauna of Calif.
TERTIARY	Neocene	Cold water marine fauna	Cold water marine fauna of Japan		Cold water marine fauna of Calif.
	Eocene	*Venericardia planicosta* Zone			*Venericardia planicosta* Zone
CRETACEOUS	Upper	*Schloenbachia* fauna of Europe	*Schloenbachia* fauna of Japan, South India, and East Africa	Queen Charlotte Islands	*Schloenbachia* fauna of California
	Lower			*Aucella* fauna of North Europe, North Asia, and Alaska	*Aucella* fauna of the Knoxville Strata in California
JURA	Upper			*Cardioceras* fauna with *Aucella* in Russia	*Cardioceras* fauna with *Aucella* in California
	Mid.		Mediterranean type in India	*Cadoceras* fauna of Alaska and the Boreal region	Mediterranean type in California
	Lower	*Arietites* fauna	*Arietites* fauna in the Indian Ocean	*Arietites* fauna of Alaska	*Arietites* fauna in California and Nevada
TRIAS	Upper		*Pseudomonotis ochotica* fauna in Japan	*Pseudomonotis ochotica* fauna in Alaska and North Siberia	*Pseudomonotis ochotica* fauna in California and Nevada
		Tropites subbullatus fauna	*Tropites subbullatus* fauna in India	*Dawsonites* fauna of the Arctic Ocean	*Tropites subbullatus* fauna in Calif.
	Middle	*Ceratites trinodosus* fauna	*Ceratites trinodosus* fauna	*Ceratites* fauna of Spitzbergen	*Ceratites trinodosus* fauna, Nevada
		Beyrichites fauna, Gulf of Ismid			*Parapopanoceras* fauna in Calif.
	Lower	*Columbites* fauna, Albania	*Hedenstroemia* fauna of India	*Olenkites* fauna of North Siberia	*Columbites* fauna in Idaho
		Tirolites cassianus fauna			*Tirolites* fauna in Idaho
			Meekoceras fauna of India	*Meekoceras* fauna of Spitzbergen	*Meekoceras* fauna in California and Idaho
CARBONIFEROUS		Atlantic type	Asiatic type in India, Japan, and China	Asiatic type in Alaska and Siberia	Asiatic type in California

GEOGRAPHIC RELATIONS OF WESTERN AMERICAN FOSSIL FAUNAS

Era	Period	Epoch	Coast Ranges		Sierra Nevada	
Cenozoic	Quaternary		Terrace			Terrace gravels
			San Pedro sandstones			
			Canyon-cutting epoch			Glacial beds
	...rtiary	Pliocene	Merced sandstones	Santa Clara lake beds		
			San Diego and Purisima sandstones	Tulare lake beds		
		Miocene	San Pablo and Etchegoin sandstones	Lake beds of Tesla, with Upper Miocene leaves	...vels	Post-volcanic gravels, with Upper Miocene leaves
			Santa Margarita sandstones			
			Coast Range revolution			Chief volcanic period
			Monterey shale			
Archaean					Archaean ?	Older gneisses of Sierra Nevada

			Coast Ranges		Sierra Nevada	Sierra Nevada
Archaean ?					Archaean ?	Older gneisses of Sierra Nevada
Paleozoic	Paleozoic	Santa Lucia	Santa Lucia limestone gneisses and granites, without definite fossils		Silurian; Grizzly	Montgomery limestone of Plumas County, with Niagara fauna
					Carboniferous; Calaveras formation	Limestones and quartzites of the Sierra Nevada, with Carboniferous fossils
Mesozoic	Triassic		Wanting?		Triassic of the Gold Belt	Sailor Canyon shales Genessee Valley limestone and shales
	Jurassic	Franciscan	Cherts, limestones, shales, and schists without definite fossils and with great intrusions of basic igneous rocks, all pre-Cretaceous, and in part possibly even Triassic in age		Oroville flora	Oroville flora, with cycads of Middle Jurassic age
					Mariposa	Mariposa shales, with marine fossils of Upper Jurassic age
					Colfax	Colfax shales and altered tuffs, and igneous rocks. Marine record almost destroyed
			Cordilleran revolution	Oregon flora: Plant beds of northern California and southern Oregon, supposed to be of Jurassic age		Cordilleran revolution
	Cretaceous	Knoxville	Knoxville shales and conglomerates	Shasta flora: Plant beds of northern California and southern Oregon, associated with Knoxville and Horsetown marine species		Erosion period. Record wanting
		Horsetown	Horsetown sandstones and shales of Shasta and Tehama counties			
		Chico	Chico sandstones	Chico flora: Plant beds in northern California associated with Chico marine species	Chico	Chico sandstones of Butte County, with marine fossils
Cenozoic	Tertiary	Eocene	Martinez sandstones		Ione formation	Wanting
			Tejon sandstones	Lake beds of Corral Hollow, with Eocene plants		Mohawk lake beds, and coal beds of Ione. Marine sandstones of Merced Falls
		Oligocene	San Lorenzo sandstones and shales			
		Miocene	Vaqueros sandstones		Auriferous Gravels	
			Temblor sandstone			Ocoya Creek sandstones, with marine fossils
			Monterey shale			
			Coast Range revolution			Chief volcanic period
			Santa Margarita sandstones			
		Pliocene	San Pablo and Etchegoin sandstones	Lake beds of Tesla, with Upper Miocene leaves		Post-volcanic gravels, with Upper Miocene leaves
			San Diego and Purisima sandstones	Tulare lake beds		
			Merced sandstones	Santa Clara lake beds		
	Quaternary		Canyon-cutting epoch			Glacial beds
			San Pedro sandstones			
			Terrace			Terrace gravels

from the igneous rocks, so that they more often arkose and greywacke than true sandstones.

Thick beds of aluminous shales, now largely changed to slates, are found in the Carboniferous and Jurassic rocks of the Sierra Nevada, and to a less extent in the Franciscan formation of the Coast Ranges. The Auriferous Slates also form the surface rocks of considerable areas in the Klamath Mountains.

Less altered shales are extensively developed in all the later formations of the state, from the Lower Cretaceous upward, although not on such a grand scale as in the older periods.

The greatest individual mass of sediments in California is formed by the Quaternary and Pliocene fluviatile deposits of the Great Valley. This mass is about four hundred miles long by fifty in width, and is several thousand feet thick in the middle, thinning out toward the edges, surpassing the enormous mass of Tertiary sediments. These valley deposits have been bored to a depth of three thousand feet, without reaching bed-rock, but there are too few deep borings for an estimate of the average thickness to be possible.

A second great mass of clastic sediments is seen in the Tertiary sandstones of the Coast Ranges, which extend nearly the entire length of the state, and have a total thickness of about fifteen thousand feet, although not all of this at any one place. A remnant of this series is seen along the western flank of the Sierra Nevada in the marine and brackish-water Ione formation, and the upland equivalent is seen in the Auriferous Gravels.

A third great mass of sandstones is found in the Cretaceous of the Coast Ranges, where a thickness of about thirty thousand feet was deposited. This thickness surpasses by far that of the Tertiary sandstones, but the areal extent is much less. These, too, overlapped on the foot of the Sierra Nevada.

Smaller masses of sandstone, now largely changed to quartzite, are seen in the early Mesozoic and Paleozoic formations of the Sierra Nevada and Coast Ranges, but nowhere forming extensive surface areas.

On the western flank of the Sierra Nevada, throughout the Gold Belt, there are in the late Paleozoic and in the late Jurassic thick beds of tuffs, or volcanic ash, now altered to greenstone schists.

These in places have a thickness of several thousand feet, but do not form considerable areas of the surface rocks.

Organic sediments.—These do not make much of a figure on the areal map of the state, but play a large part in its economic history. They are limestones, siliceous shales, and plant accumulations in the form of coal or lignite.

The limestones are entirely of organic origin, with the exception of some smaller occurrences of late spring deposits, or calcareous tufa, which, however, are large enough to be used in the manufacture of cement.

The great masses of limestone are confined to the Paleozoic and early Mesozoic, though as late as the middle of the Jurassic period there are some large beds of limestone. They are formed of ground-up shells, corals, and foraminifers that lived in quiet, clear waters, but are now largely crystalline, most of the evidence of their organic origin having been destroyed in the great mountain-making revolutions that have passed over them. The formation of limestone on a large scale in California was confined to epochs that we know from other evidence were warm, and also to epochs when sheltered, clear seas covered portions of the state. In such seas corals and foraminifers abounded, and the evidence of their rock-forming activity is still visible in the coral reefs of the Paleozoic and Triassic, and the Fusulina limestone of the Carboniferous.

From the middle of the Mesozoic up to the Eocene it was still warm enough at times for reef-building corals, and foraminifers to have flourished in the seas of California; but the warm epoch of the Middle Jurassic was a time of igneous activity, and during the Cretaceous there was too much sand and mud poured into the water for these organisms to find a favorable habitat.

Limestones, at least in part formed by corals, have a thickness of several thousand feet in the Cambrian of Inyo County, but the areal extent is unknown. The Devonian of Shasta and Siskiyou counties shows coral reef rock to the thickness of several hundreds of feet, of small area. These are all surpassed in the great masses of Carboniferous limestone, of the White Mountains, the western flank of the Sierra Nevada, and the Klamath Mountains, where the lenticular beds sometimes attain a thickness of two thousand feet.

The Santa Lucia limestone, in the Coast Ranges, of doubtful Paleozoic age, also occur in large beds, amounting to several hundred feet in thickness, now changed to marble.

The Upper Triassic of Shasta and Plumas counties has lenses of limestone in places four or five hundred feet thick, forming important topographic features, and largely formed by the agency of corals.

The Franciscan series of the Coast Ranges has similar limestone masses of lenticular form, amounting in places to a few hundred feet in thickness, and wholly destitute of fossils, except a few traces of foraminifers.

The Cretaceous lacks limestone beds, except a local accumulation of shell limestone in the Knoxville formation of Colusa County, where a thickness of only a few feet is developed.

The Eocene of the Santa Cruz Mountains has some thin beds of limestone, and the Miocene of Santa Barbara, San Luis Obispo, and Orange counties has shell limestone amounting to as much as fifty feet in thickness. With the exception of these local occurrences there are no limestone masses in the marine beds of California from the middle of the Jurassic to the Quaternary, the Jurassic and Knoxville being characterized by thick beds of shale, and the other formations, from the Horsetown up, by enormous beds of sandstone.

Siliceous organic sediments.—Among the most remarkable features of the stratigraphy of California are the thick beds of siliceous organic sediments. In the Monterey shale of the Middle Tertiary in the Coast Ranges such sediments are extensively developed, and in places reach a thickness of five thousand feet. These are not shales in the ordinary sense, for they are chiefly organic in origin, the remains of microscopic diatoms and radiolaria. Similar deposits are known also in the Eocene of the middle Coast Ranges, but on a smaller scale. These organic siliceous shales are of great economic importance, for they have furnished nearly all of the petroleum of California.

Similar masses of siliceous organic sediments are known in the Coast Ranges in the Franciscan formation, of the earlier Mesozoic, but they are no longer shales, rather hard, flinty rocks, with the organic matter long since removed, and the fossil tests of radiolaria almost entirely destroyed, so that the rocks now show little resemblance to organic sediments.

In the Mother Lode region of the Sierra Nevada there are somewhat similar chert masses, in beds supposed to be Jurassic in age. These too are probably of radiolarian origin. In the Middle Triassic of Shasta County a series of siliceous shales almost without sand grains, and about two thousand feet thick, likewise was probably formed partly from the shells of siliceous organisms.

The Lower Carboniferous and the Devonian of Shasta and Siskiyou counties also contain many hundreds of feet of fine-grained so-called siliceous shales that are probably, at least in part, metamorphosed organic sediments. Shells of diatoms and radiolaria are extremely rare in all these older beds, but organic silica is very soluble, and even a slight degree of metamorphism destroys the delicate tests, and thus obliterates the evidence of their origin.

Coal deposits.—During the Eocene epoch plant remains accumulated to a considerable extent in the swamps of the old embayment of California, especially along the western flank of the Sierra Nevada near Ione, the Coast Range island area of the Mt. Diablo region, and in the middle Coast Ranges of Monterey, San Benito, and Fresno counties. These leaf beds have since been compacted into lignite, and in a few places into true coal.

Chemical deposits.—In Kern, San Bernardino, San Diego, and Inyo counties there are extensive chemical precipitates of salt, soda, borax, and gypsum, concentrates from the old lakes and salt pans of the arid region, from Tertiary up to the present. The areal extent is not large, but they are scattered over enormous stretches of country, and are of great present or prospective economic importance.

Comparative Rate of Formation of Calcareous and Arenaceous Sediments

Most estimates of the relative rate of formation of calcareous and arenaceous sediments are merely conjectural. A method is here suggested by which a somewhat more reliable estimate may be made. It is based on the comparative thickness of a single formation in the Californian region with that of the same formation in another region. This can be reliable only when the entire formation is represented in both regions compared, and when the conditions are reversed. We have two such cases in the Carboniferous of California and the western

part of the Mississippi Valley region, and in the Cretaceous of the same regions.

The McCloud limestone of California represents nearly the whole Coal Measures, with only a small part of the upper division absent, and it is all rather pure limestone with a thickness of about two thousand feet. The Coal Measures section of Arkansas embraces all but the uppermost part of the formation, and the thickness is approximately twenty thousand feet, if we leave out the Poteau group, which is probably higher than the top of the McCloud limestone of California. This would indicate that it takes approximately ten times as long for a foot of limestone to form as it does for a foot of sandstone.

A similar conclusion may be drawn from a comparison of the Cretaceous sections of the two regions; and here the West Coast has an arenaceous section, while the Cretaceous rocks of the Southwest are in places entirely calcareous, a reversal of conditions from those of the Carboniferous.

The Cretaceous section of northern California shows a thickness of about thirty thousand feet, all sandy, and evidently deposited in shallow water in a synclinal trough, just as was the Coal Measures sandstone of Arkansas and Oklahoma. The Cretaceous beds of the Southwest, ordinary marls and chalky limestones, have, where not mixed with sandy deposits, a thickness of about three thousand feet. This again indicates that it takes about ten times as long for the accumulation of a foot of limestone to accumulate under ordinary conditions as it does for a foot of sandstone.

Of course the thicknesses vary in different parts of the same region, and at best are only rough estimates; also we cannot be sure in widely separated regions whether we have exactly the same geologic units represented in the sections compared. Also it is not at all likely that all limestones or all sandstones are laid down at even approximately the same rates. Still the agreement of the figures is too great to be accidental.

If we accept this ratio of ten to one for rates of formation of sandstone and limestone, we have a means of estimating the relative length of time consumed in laying down the rocks of the various formations, even when their lithologic character is different. Thus

the Triassic of the Great Basin region, with only four thousand feet of calcareous sediments, probably represents at least one-third longer time than the Cretaceous of California, with its thirty thousand feet of sandy beds. The Tertiary formations of California, which are about fifteen thousand feet thick, represent about one-half the time of the Cretaceous, which is twice as thick, and about one-third of the time of the Triassic of this region, which is hardly one-fourth as thick. The other formations are too incompletely developed here, or too varied in composition, for any reliable estimate of their relative length of time to be made. The Carboniferous section is complete, but has sandstones, shales, limestones, and tuffs alternating in such a manner that, with our present knowledge, it is hardly possible to estimate the entire system in terms of limestone.

NEOCENE FORMATIONS OF CALIFORNIA

Because of the numerous formations that have been named in the Tertiary of California, and the numerous changes that have recently been made in the nomenclature and succession of these formations, a detailed table is here added, for the sake of those interested in West Coast geology, and not familiar with its details.

The great development of petroleum in California and the intense activity of geologists in that field are responsible for the embarrassing wealth of formational names in the Neocene. They are necessary, at present, for it is a difficult matter to correlate the minor horizons with accuracy over such a large region.

is Obispo	Salinas Valley		Santa Cruz		Mt. Diablo Region	
e section of so Robles, osed to be of water origin	Paso Robles	Gravels like those of the type section	Merced	Marine beds of Lake Merced and fresh-water beds of Santa Clara — Santa Clara	Berkleyan	Freshwater Pliocene and Miocene of the Berkeley Hills
			Purisima	Marine beds of Half Moon Bay with Pecten healeyi		
tfully referred his horizon. nay be the valent of the a Margarita	Etchegoin	Sandstones with Scutella gibbsi and Pecten wattsi			San Pablo	Type section on San Pablo Bay with Pecten pabloensis and Astrodapsis tumidus
al sandstones Ostrea titan amiosoma garia, and n estrellanus	Santa Margarita	Type section of Santa Margarita with Ostrea titan Tamiosoma gregaria and Pecten estrellanus	Santa Margarita	Sandstones with Ostrea titan and Astrodapsis antiselli	Santa Margarita	Kirker's Pass beds with Santa Margarita fauna Sandstones with Ostrea titan and Pecten crassicardo
h discus beds		Pecten discus beds				
tomaceous es, like the al Monterey	Monterey	Type section of Monterey shale	Monterey	Bituminous diatomaceous shale	Monterey	Monterey shale
lstones with oma gravidum tella ocoyana d Mytilus athewsoni			Temblor	Sandstones with Agasoma gravidum Turritella ocoyana and Pecten andersoni	Contra Costa	Sandstones with Agasoma and Turritella ocoyana
ve sandstones with tella inezana en magnolia and s mathewsoni	Vaqueros	Type section of Vaqueros, massive sandstones of the Santa Lucia Mts. with Turritella inezana	Vaqueros	Sandstones with Turritella inezana		

Quaternary	Faunal Zone	San Diego	Los Angeles	Ventura	Santa Barbara	Kern	Coalinga	San Luis Obispo	Salinas Valley	Santa Cruz	Mt. Diablo Region
Pliocene, Upper, Merced	Zone of Scutella interlineata		Upper Fernando Deadman Island beds with Pecten caurinus		Upper Fernando with Pecten bellus		Tulare: Lake beds with Pliocene fauna with some brackish-water beds	Paso Robles: Type section of Paso Robles, supposed to be of freshwater origin	Paso Robles: Gravels like those of the type section	Merced: Marine beds of Lake Merced and fresh-water beds of Santa Clara	
Pliocene, Lower, San Diego	Zone of Pecten healeyi	San Diego: Sandstones with Pecten healeyi and Pecten hemphilli Type section	Fernando formation: Middle Fernando with Pecten hemphilli	Fernando formation: Middle Fernando with Pecten healeyi	Fernando formation: Middle Fernando					Marine beds of Half Moon Bay with Pecten healeyi	Berkeley: Freshwater Pliocene and Miocene of the Berkeley Hills
Miocene, Upper, San Pablo	Zone of Pecten wattsi and P. coalingaensis	Carrizo formation: Sandstones with Pecten carrizoensis and P. cerrosensis					Etchegoin formation: Beds with Pecten wattsi and P. coalingaensis	Pismo formation?: Doubtfully referred to this horizon. It may be the equivalent of the Santa Margarita	Etchegoin: Sandstones with Scutella gibbsi and Pecten wattsi		San Pablo: Type section on San Pablo Bay with Pecten pabloensis and Astrodapsis tumidus
	Zone of Pecten oweni		Lower Fernando	Lower Fernando with San Pablo fauna	Lower Fernando						
Santa Margarita	Zone of Pecten estrellanus and Trophon carisaensis						Jacalitos beds with Pecten oweni	Santa Margarita: Typical sandstones with Ostrea titan Tamiosoma gregaria, and Pecten estrellanus	Santa Margarita: Type section of Santa Margarita with Ostrea titan Tamiosoma gregaria and Pecten estrellanus	Sandstones with Ostrea titan and Astrodapsis antiselli	Kirker's Pass beds with Santa Margarita fauna
	Zone of Tamiosoma and Ostrea titan						Coalinga formation: Beds with Tamiosoma gregaria, Ostrea titan, and Pecten estrellanus				Sandstones with Ostrea titan and Pecten crassicardo
	Zone of Pecten discus				Pecten discus beds			Pecten discus beds	Pecten discus beds		
Monterey			Puente shales: Diatomaceous shales resembling the Monterey (Modelo)	Modelo formation: Flinty shales resembling the Monterey	Monterey: Diatomaceous shales, resembling the Monterey	Monterey: Bituminous shales	Doubtfully referred to the Monterey	Monterey: Diatomaceous shales, like the typical Monterey	Monterey: Type section of Monterey shale	Monterey: Bituminous diatomaceous shale	Monterey shale
Lower, Vaqueros	Zone of Agasoma and Pecten andersoni		Puente sandstone: Sandstones with fauna like that of the Ocoya formation	Barren sandstones		Ocoya Creek beds: Barker's ranch beds with Agasoma barkerianum Agasoma kernianum and Pecten andersoni	Temblor: Type section of Temblor, with fauna like that of the Ocoya Creek formation	Temblor: Sandstones with Agasoma gravidum Turritella ocoyana and Mytilus mathewsoni		Sandstones with Agasoma gravidum Turritella ocoyana and Pecten andersoni	Sandstones with Agasoma and Turritella ocoyana
	Zone of Pecten magnolia and Turritella inezana		Vaqueros: Sandstones with Turritella inezana	Vaqueros: Sandstones with Turritella inezana and Mytilus mathewsoni	Vaqueros: Sandstones with Turritella inezana and Pecten magnolia		Vaqueros	Vaqueros: Massive sandstones with Turritella inezana Pecten magnolia and Mytilus mathewsoni	Vaqueros: Type section of Vaqueros, [illegible] of the Santa Lucia Mt with Turritella inezana	Vaqueros: Sandstones with Turritella inezana	

SYNOPSIS OF QUATERNARY HISTORY OF CALIFORNIA

<table>
<tr><td>RECENT</td><td colspan="2">Subsidence epoch of Golden Gate and other bays</td><td colspan="3">Invasion of Golden Gate River System by tide water and formation of the harbors of the West Coast. This subsidence has been going on until very recent time, for Indian shell mounds around the Bay of San Francisco are partly flooded</td></tr>
<tr><td rowspan="5">QUATERNARY</td><td>Terrace epoch</td><td>Terrace</td><td colspan="3">Period of uplift and scouring out the channels filled during the San Pedro epoch, forming terraces in the fluviatile sediments of San Benito Valley, and nearly all the valleys of the Coast Range. The youngest (lowest) terraces of the San Pedro truncate the upper San Pedro beds and are later than they. The older (higher) wave-cut terraces of the West Coast probably date back to the Sierran epoch</td></tr>
<tr><td>Upper San Pedro</td><td rowspan="2">Champlain</td><td rowspan="2">Epoch of depression along the coast
Coast stood 300–700 ft. lower than now</td><td>Warm water marine fauna</td><td rowspan="2">Epoch of filling pre-existing valleys with gravels and other fluviatile sediments. Seen in the Salinas Valley, Santa Clara Valley, San Benito Valley, and the Great Valley</td></tr>
<tr><td>Lower San Pedro</td><td>Cold water marine fauna</td></tr>
<tr><td rowspan="2">Sierran epoch. Probably longer than all the rest of the Quaternary</td><td>Glacial</td><td colspan="2" rowspan="2">Period of elevation of the West Coast, forming the great canyons off the Sierras and the submerged canyons of the coast. A period of no marine sediments (now exposed). In part contemporaneous with the Glacial epoch, for the glaciers of the Sierra Nevada came down some of the Canyons.
The West Coast then stood about 3,000 ft. higher than now, as shown by the submerged Monterey Bay Canyon at a depth of 3,000 ft.</td><td rowspan="2">The principal terracing along the coast took place at this time, and also the Channel Islands were connected with the mainland, as shown by the Santa Rosa Mammoth</td></tr>
<tr><td>Pre-Glacial</td></tr>
<tr><td>PLIOCENE</td><td>Merced Beds</td><td></td><td colspan="3">Period of depression and filling of troughs with marine Pliocene sediments, and formation of great Pliocene lakes above sea-level</td></tr>
</table>

THE APPALACHIAN FOLDS OF CENTRAL PENNSYLVANIA

ROLLIN T. CHAMBERLIN

The observational basis of this study of the Appalachian folding in central Pennsylvania was laid during a special trip on foot from Tyrone to Harrisburg during the summer of 1905. The chief purpose was to measure the dip-angles of the strata at as many stations as possible, that they might be subsequently plotted to scale as a groundwork for restoring the folded structure. Nearly 400 dips were measured, but on plotting them and attempting to restore the structure it was found that they only scantily covered several portions of the section where critical data were especially desirable. This proved to be particularly true of the neighborhood of Harrisburg, where the anticlinal arches are overturned and the shales and slates are so crumpled that, with the time available, it was not possible to trace out many of the minor, but none the less important, complications of structure. As a result it was felt that the material at hand was scarcely adequate for a serious study, and in the hope that a later opportunity might arise to make a further search for the desired data, the work was laid aside. But up to the present no opportunity to again visit this region has presented itself and it has seemed, on reflection, best to proceed with the original purpose, since this was not so much to gain a truer view of this particular case of folding, as to put to working trial certain recent suggestions as to the deductions that may be drawn from data of this sort. In Chamberlin and Salisbury's *Geology*, Vol. II, pp. 125–126, a method is given for deducing the thickness of the shell involved in folding. The present study is a preliminary attempt to make a special application of this method and to see what collateral suggestions might spring from it in practice. For this purpose it is not so material, though it is desirable, that the actual data be complete. In the very nature of the case, most studies of this class must, for the present, deal with incomplete data, since

each case has certain indeterminable factors. The necessary deficiencies, however, only make the more serviceable any deductions that can be drawn from such data as are available, if they can be so handled as to extend their significance. It has seemed possible therefore that a discussion based on data that have even serious shortcomings may have some value. It is only because it is hoped that this might prove true that it has been decided to carry out these studies on the present observational data.

The tract of the Appalachian Mountains most readily accessible for dip studies is that which lies along the main line of the Pennsylvania Railroad between Tyrone, in Blair County, and Harrisburg. From Tyrone to Mount Union the railroad, following the Juniata River, crosses the folds in a fairly straight line at right angles to their strike and affords a very good section. But just beyond Mount Union the Juniata turns sharply to the northeast and runs for twenty-five miles parallel to the strike, as far as Lewistown. This offset necessitates a division of the whole cross-section into two parts. From Lewistown to Harrisburg the folds are crossed generally at right angles to the strike with the exception of a few minor curves. This constitutes the second portion. Inasmuch as the second portion commences near Lewistown at the point corresponding to that where the first section left off near Mount Union, it would seem that no great structural error is introduced by ignoring the shift and uniting the two separate parts into one section.

At every available rock-outcrop along each of these lines, the dip of the strata was read with a clinometer compass, using the telegraph poles which are set thirty-eight to the mile as a means of locating the stations. For rapid work of this sort the spacing of the telegraph poles may be used so as to give quite closely the distance intervening between the locations of outcrops. Allowance, of course, must be made whenever the railway-line crosses the folded structure obliquely and curvingly, instead of normal to the strike. Wherever there occurred sudden changes in the angle of dip, or small local folds, diagrammatic sketches were made of the rock-face, and on these sketches the clinometer readings were recorded at the appropriate points. Where there were good outcrops the details of the folded structure were readily discerned, but unfortunately there were

frequently considerable areas over which suitable rock-exposures were wanting. In all, nearly four hundred dip-angles were recorded between the nearly horizontally bedded uplands west of Tyrone and the outskirts of Harrisburg.

In plotting the dip-angles to scale on co-ordinate paper, it was found most convenient to represent the distance between two telegraph poles, or one thirty-eighth of a mile, by two millimeters, which was the smallest unit available on the style of paper used. Therefore each mile in nature is represented by seventy-six millimeters on paper. From these plotted dip-angles and the available information upon the location of the contacts of the different formations and their varying thickness, partly obtained in the field and partly from the reports of the Pennsylvania State Survey, the writer has attempted to restore the complete folded section as it is supposed to have been before the ridges were truncated by erosion. Necessarily the uncertainties in the projection of folds are so considerable that this can be regarded only as a rough approximation to the original conditions following the period of folding. It is on the basis of this restored section that the present study has been made.[1]

THE SHORTENING OF THE CRUST

Several estimates of the amount of crustal shortening involved in the folding of these mountains have already been made. Lesley placed the lateral movement of the Appalachian thrusting at forty miles.[2] Claypole[3] divided the folded tract into two parts; the first from the approximately horizontal formations on the northwest, across the eleven principal ranges of mountains to Blue Mountain on the southeast, a total of forty-nine miles; the second, sixteen miles in length, crosses only the Cumberland Valley. By deducting twenty miles of the first section for the flattish tops of the anticlinal crests and

[1] For an alternative profile of the Appalachian flexures, a series of dip-readings was made along the Susquehanna River between Harrisburg and the vicinity of Williamsport. But this proved to be a less representative section, and since, in addition, good outcrops were less numerous, only the Tyrone-Harrisburg section will be treated in this article.

[2] J. P. Lesley, cited by Chamberlin and Salisbury, *Geology*, Vol. II, p. 125.

[3] E. W. Claypole, "Pennsylvania before and after the Elevation of the Appalachian Mountains," *Am. Nat.*, Vol. XIX (1885), pp. 257–68.

the bottoms of the synclinal troughs, and assuming that the remaining twenty-nine miles of strata possessed an average dip of 40°, he arrived at the conclusion that these forty-nine miles of strata, if flattened out, would measure fifty-eight miles. It is not easy to determine the number of folds occurring in the Cumberland Valley, but on the basis of the thickness of strata included in these plications, Claypole reasoned that there could scarcely be less than eight overthrown anticlinal arches in the sixteen miles considered. Adopting Professor Rogers' lowest angle of dip for the southeast legs (45°) and 60°, his lowest estimate for the northwest limbs, he calculated that ninety-five miles of strata had been compressed into these sixteen miles. Considering both sections together, this would mean that a tract of the earth's surface measuring originally one hundred and fifty-three miles had been compressed into sixty-five miles. As Claypole frankly stated, this estimate took account only of the eleven principal folds and ignored the minor flexures.

The present estimate of crustal shortening is made from a measurement of the strata in the plotted cross-section formed as above stated and made to include as much as possible of the minor contortions of the beds. The data for these sections were obtained at the railroad horizon. From the dip-angles, the locations of the formation-contacts, and the thicknesses assigned to the formations, the whole series of beds up to the top of the Pottsville conglomerate were projected over the entire restored section. But as the youngest of these arched strata had to be projected many thousands of feet above the railroad-level to do this, it is to be noted that the farther up in the stratigraphic series the restoration of structure is carried, the more uncertain does it become. The separate strata, being of different material and offering varying resistance to the thrust, cannot always be supposed to wrinkle alike. Minor flexures and local bits of crumpling may fade out in passing up or down, and new ones appear. Hence for the purpose of measuring the length of strata over this section it seemed advisable to choose the stratigraphic horizon which remained nearest to the railway-level. It is to be recognized, of course, that the maximum amount of crustal shortening was probably suffered by the surface beds and that the folds slowly die out downward, but it is believed that whatever lessening of the flexures there may be in the

first few thousand feet would be likely to be more than offset by the probable error in projecting folds to such a distance from the observed dips.

For the division from Tyrone to Mount Union (Figs. 1 and 2) the thin, but strongly resistant Oriskany sandstone was chosen for

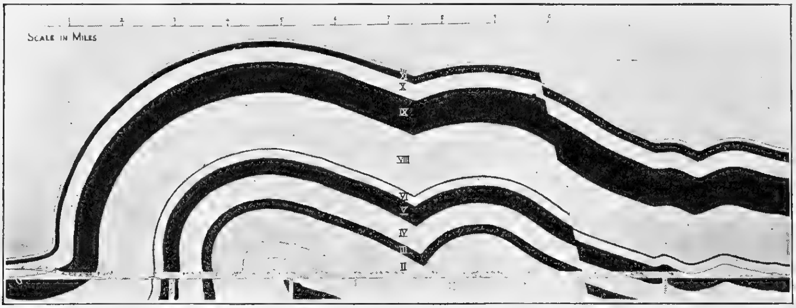

FIG. 1.—A reconstruction of the folded section from the essentially horizontally bedded uplands west of Tyrone nearly to Petersburg. East of Tyrone the dip-angles are plotted on the horizontal line which represents the railroad-level; on the uplands west of Tyrone they are plotted according to the surface topography. The numbers representing the formations are those used by the Pennsylvania Geological Survey: II, Trenton and Calciferous; III, Hudson River shales; IV, Oneida and Medina; V, Clinton; VI, Lower Helderberg; VII, Oriskany; VIII, Chemung; IX, Catskill; X, Pocono; XI, Mauch Chunk; XII, Pottsville conglomerate.

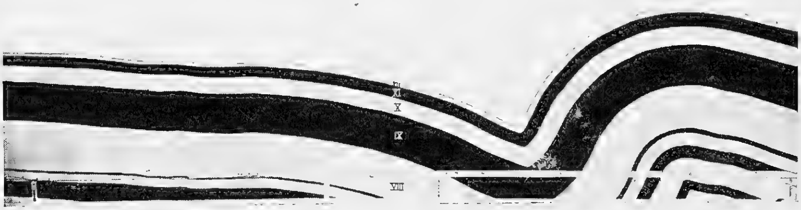

FIG. 2.—Continuation of section from Petersburg to Mount Union

measurement as likely to give the most reliable results. In the second section the Oriskany was also measured as far as the crest of the anticline just before the prominent fault near Iroquois Station (Fig. 4). At the very crest-point of this anticline the measurement was shifted from the Oriskany to the base of the Catskill since the strata soon take a tremendous dip which carries the Oriskany far below the surface. This shift appears permissible since the fold is approxi-

mately symmetrical. The measurement then followed the base of the Catskill to the end of the section (Fig. 5).

To follow and measure the contortions of these two selected formations throughout their length, a copper wire was used. Placed upon

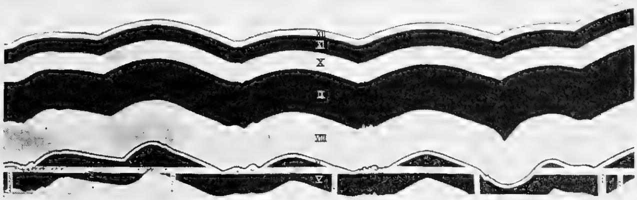

FIG. 3.—Reconstructed section between Lewistown and Durward

FIG. 4.—Section between Durward and Aqueduct Station

FIG. 5.—Continuation of section from Aqueduct Station to Harrisburg

the plotted cross-section, this was bent so as to be exactly superimposed upon the line to be measured. This wire, when straightened out and measured, represented very closely the length of the chosen stratum along its tortuous course. As the cross-sections were plotted on millimeter paper all measurements were made in that unit.

The total length of the Oriskany stratum as reconstructed in the cross-section from the west end of the folded region to Mount Union (Figs. 1 and 2) was found to measure 2,602 millimeters. The straight-line distance between these points measured on the railroad-level is 2,288 millimeters. The length of the top line of the restored section (the top of the Pottsville) was also measured as a check. It was found to be 2,618 millimeters. If 2,602 millimeters, the length of the Oriskany along the dip, represents the original length of that stratum before the folding took place, and 2,288 millimeters represents the present horizontal length of the section under consideration, there must have been a shortening of this formation to the extent of 314 millimeters, or 12 per cent. of the original length. On the scale used, seventy-six millimeters in the cross-section represents one mile in nature. Converting the figures obtained from a measurement of the plotted section into miles, the length of the Oriskany (2,602 millimeters) becomes 34.2 miles and the horizontal distance, 2,288 millimeters, is equivalent to 30.1 miles. Neglecting other factors, the shortening amounts, therefore, to 4.1 miles.

In the second section the length of the Oriskany from the beginning at Lewistown to the crest-point of the anticline above mentioned between Baileysburg and Iroquois Station was found to measure 1,789 millimeters. At this point the shift was made to the base of the Catskill. The lower limit of this formation, followed to the point where it rises above the railroad-level about half a mile southeast of Marysville, gave a dip distance of 1,070 millimeters. The sum of these two dip measurements gives 2,859 millimeters as the length of these strata between Lewistown and the contact of the Catskill with the Chemung close to the Susquehanna bridge five miles above Harrisburg. On the same scale the present horizontal distance between these points is 2,399 millimeters. This indicates a crustal shortening due to the flexing of the beds, which amounts to 460 millimeters, or 16.1 per cent. of the original length. Translated into miles these figures are respectively 37.6 and 31.5 miles, signifying a shortening of 6.1 miles. The total shortening, therefore, from the beginning of the section west of Tyrone to the point between Marysville and the Susquehanna bridge amounts, on the basis of the assumptions made, to 10.2 miles, 71.8 miles having been compressed to 61.6 miles.

Southeast of the Susquehanna bridge above Harrisburg the data obtained were inadequate and unsatisfactory. The strata to which we must look for guidance here are Hudson River shales and slates, and they are mashed and disturbed to such an extent that often there is danger of mistaking secondary structures for bedding. Wherever observed these beds all dip southeastward at angles varying from 50°–80° in such a way as to indicate overturned folds. But these soft shales furnish the poorest sort of criterion for determining the true character of the folding, because a weak formation of this sort may be much wrinkled, crushed, and appressed, while the stronger strata above may have been merely bowed upward and may not have suffered crumpling to the same extent. In projecting the younger formations over these folded shales, the wrinkles were made to die out slowly. The shale layers were allowed considerable thickening and thinning, but in the stronger layers above little of this distortion was taken into account. It may well be that considerably more thickening of the layers on the crests and troughs, and thinning on the limbs of the folds should be allowed in the upper formations. Since the observed data for this slate and shale belt are so meager and the restoration of the younger formations which once covered this region is so precarious because of this limited knowledge, and because the whole is so much a matter of personal opinion, it has not seemed advisable to state any measurements made upon the reconstructed curves. Some of the layers were measured, however, and upon this basis a rough guess that the original length of these strata was about twice their present horizontal length is ventured. They can scarcely have suffered much less shortening than this, though they may have suffered much more. Claypole believed that these overturned folds resulted from such intense crumpling that into each horizontal mile of present distance there have been squeezed what were originally six miles of flat-lying strata,[3] but this figure seems to me somewhat excessive.

To put these figures together, we have, on the basis of the assumptions made, and subject to other limitations to be mentioned shortly, 71.8 miles reduced to 61.6 miles west of the Susquehanna bridge, and 9.5 miles jammed into the present distance of 4.75 miles between Harrisburg and the Susquehanna bridge, making a total west of Harrisburg of 81 miles compressed into 66 miles.

The various elaborate factors which enter into the problem of crustal movement, and which embarrass quantitative determinations of the shortening, have been ably discussed by Van Hise.[1] These embarrassing factors include the following: (1) The thickening and thinning of the strata in the different parts of the sharper folds. The thickening and thinning are uncertain variables, for which it is difficult to make allowance when only a very limited portion of the whole fold can be observed, as is usually the case. (2) The variation in the closeness of the folding in passing upward or downward from the layer on which the observations were made. The farther upward from the recorded data the folds must be projected, obviously the greater the error likely to creep in. It was for this reason that, in the case in hand, the measurements on the plotted section were made along those strata which departed the least from the railroad horizon. (3) Subsequent relaxation of the strata under the influence of gravity. This may take the form of gliding on the limbs of the folds where a new series of corrugations may be developed; it may also be manifested in the opening of fissures and in the phenomena of normal faulting. The effect of these secondary phenomena involving dilatation of the surface shell subsequent to the folding period is to cause an overestimate of the extent of the crustal shortening. But the quantitative importance of gravity wrinkling in the Appalachian region arising from relaxation and creep since the period of folding is, for the present at least, impossible of determination, but it is probably not seriously large.

It is also probable, on the whole, that in addition to the folding the lateral thrusts have caused a certain amount of mashing and compacting of the material of the beds. A few measurements upon the wax-and-plaster folds developed experimentally by Willis[2] show that the decrease in the length of the layers due to mashing alone, varied from 1 up to 10 per cent. of the original length. The total shortening of all kinds in the illustrations selected for measurement varied from about 15 per cent. to somewhat more than 60 per cent.

[1] C. R. Van Hise, "Estimates and Causes of Crustal Shortening," *Jour. of Geol.*, Vol. VI (1898), pp. 10–64.

[2] Bailey Willis, "The Mechanics of Appalachian Structure," *Thirteenth Ann. Rept., U.S. Geol. Surv.* (1891–92), Pt. II, pp. 211–82.

The variation in the amount of linear reduction due to mashing appears to correspond to differences in the character of the material used in the experiments. As a rule the softer the material in the layers the greater the degree of mashing; when more plaster and less wax and turpentine stiffened the layers, they were much less compacted. An average figure for the shortening of the layers due to mashing in these experiments by Willis would seem to lie in the neighborhood of 5 per cent. In the case of the Appalachians, however, the amount to be allowed for shortening due to mashing of the strata in addition to that resulting from the corrugation must be left largely to conjecture, but as the rock-formations are relatively much stiffer than the wax-and-plaster layers used in the experiments, it would seem likely that the figure for the mountains should be considerably less than 5 per cent.

Tending to offset the shortening due to the mashing of the rocks is the subsequent elongation of the strata arising from the opening of fissures, jointing, cementation by infiltration, and the penetration of igneous intrusions. Several former fissures near the junction of the Juniata with the Susquehanna have been rendered conspicuous by the intrusion of Mesozoic trappean magmas which have solidified within them. No attempt at any quantitative estimate of their importance in crustal shortening is made here. Whether the importance of these various secondary factors is material and whether, if ignored, the balance of their sum-total tends toward an overestimate, or an underestimate, of the true extent of the crustal shortening, is here left to the individual judgment of each geologist guided by his own experience and insight. The results reached later may have some reflex bearings on these points.

THE HEIGHT OF THE FOLDED TRACT

For a study of the dynamics of crustal warping and the nature and dimension of the mountain-building movements, one of the necessary factors to be determined is the amount of vertical bulging. To determine the extent of the upswelling connected with the folding it is necessary to measure the height of the newly folded ranges above the average height of the same region before the movements began. The first requirement is a base plain to which may be referred the

attitude of the land surface before the folding took place; the second requirement is a visible base-line available at the present day, above which the projection of the folded tract is to be measured. In view of the fact that the critical period of folding occurred as far back in geologic history as the close of the Paleozoic, and in view of the still more compromising fact that other diastrophic movements have disturbed the Appalachian belt since that time, it might at first seem that such planes of reference could not reasonably be hoped for. But fortunately the physiographic history of the Appalachians has been admirably arranged to meet the requirements of the case.

The last beds to be deposited in the present mountain tract were the upper strata of the Coal Measures. From the nature of these beds, particularly the persistence of coal repeated in a considerable number of separate seams over adjacent areas of wide extent, it is confidently inferred that the Appalachian region during the Upper Carboniferous must have constituted an almost perfect plain of sedimentation, at times just at, or a few feet above, the sea-level, and at other times but slightly submerged. The very considerable areas over which individual coal-seams may be traced testify to the uniformly level condition of the region. It was this rather remarkable plain of sedimentation, warped and wrinkled by the throes of the dying Paleozoic, that rose into the great Appalachian plications.

On the other hand, the mountains thus formed had their day and were gone before the end of the Mesozoic, when a new plain had been established. The Kittatinny base-level, strikingly visible even today in the level crest-lines of all the major ridges of this portion of Pennsylvania, shows that by the close of the Cretaceous, the former mountain tract had been beveled till the land again stood close to the sea-level.

Thus the Appalachian region started approximately from the sea-level, was thrust up into tremendous folds, and then planed down by erosion again essentially to the level of the sea. If no other diastrophic movements intervened to complicate the case, the total upwarping of the crust should be expressed by the average height of the freshly folded tract above the sea, and if the height of the sea relative to the land of this area remained the same till the Kittatinny base-plain was established, that plain should constitute an absolute

base above which the hypothetically restored folded section could be measured. But the sea-level undoubtedly did not remain stationary through such a long period of time. Such a ponderous series of mountain-masses must have been subject to some settling. Possibly a mathematical analysis of the mechanics involved might furnish a theoretical figure for the possible isostatic changes, but the problem is quite beyond the reach of the present paper.

Some rise of ocean-level is also to be expected on account of the filling of the ocean-basin with the material removed from the mountains in the process of peneplanation, and obviously sedimentation in other portions of the oceanic area would be equally effective in changing the water-level; and hence the great ramification of the problem.

Some crustal warping also appears to have occurred at the east during the early Mesozoic. The Newark series of sediments, which were laid down in local depressions in southeastern Pennsylvania during the Triassic, seem to imply a certain amount of downwarping in that region.[1] Later, at the close of the Triassic, or early in the Jurassic, the deposition was stopped by the reversal of the conditions which started it.[2] A moderate elevation with tilting affected the Newark beds. But to what extent these warpings in the eastern part of the state affected the mountain-section under consideration is uncertain, and whether the sum-total of the movements should be regarded as upward or downward must remain, for the present, largely a matter of conjecture.

But in general the period of erosion and base-leveling which was inaugurated by the mountain-building at the close of the Paleozoic and which resulted in the Kittatinny plain was one of comparative quiescence and, on account of its freedom from the more important dynamic movements, the present case is probably as favorable as any other which could be selected.

It will therefore be assumed that when the folding commenced the formations were practically horizontal and the upper surface of the youngest beds essentially at sea-level. It will also be assumed that the Kittatinny base-plain in turn represents somewhat approxi-

[1] Chamberlin and Salisbury, *Geology*, Vol. III, pp. 7–9.

[2] W. M. Davis, "The Rivers and Valleys of Pennsylvania," *Nat. Geog. Mag.*, Vol. I (1889), p. 196.

mately a horizon equivalent to the sea-level from which the strata were upwarped. Estimates of the height of the folded tract may therefore be measured from the Kittatinny plain as a base. In this way the Tertiary uplifts and any other disturbing factors since the Cretaceous are eliminated.

In the reconstructed section no beds younger than the Pottsville conglomerate were included, for the reason that no younger formations now occur in the region studied. It seems highly probable, however, that the Allegheny, Conemaugh, Monongahela, and possibly the Dunkard formations once covered this portion of the Appalachians, and were incorporated in the folds but have since been removed by erosion. These formations vary considerably in thickness in different localities. In Westmoreland County the Lower Productive, Lower Barren, Upper Productive, and Upper Barren Measures have a total thickness of 1,477 feet.[1] Campbell gives 1,540 feet for the Coal Measures above the Pottsville in southwestern Pennsylvania.[2] These are on the southwest side of the area under consideration; in the anthracite regions to the northeast, the Coal Measures appear to be thicker—in the northern field 1,800 feet, in the middle 1,500 feet, while they attain a total aggregate of 2,500 feet in the southern field, and it is not certain that some layers may not have been removed by erosion from each of these districts.[3] The thickness of these formations over the Tyrone-Harrisburg mountain-section was perhaps of about the same order of magnitude, though this must always remain a matter of conjecture. A belt representing the missing Coal Measures therefore belongs above the Pottsville, but was omitted from the cross-sections because of the uncertainty as to the thickness and former extent of these beds. An average figure for the thickness of these missing beds is to be added to the height of the folded section in the following estimates.

But the Kittatinny base-level maintains also somewhat fluctuating elevations above the railroad tracks. Generally about 1,000 or 1,100 feet separate the two horizons, but at points in Huntingdon

[1] J. J. Stevenson, *Second Geol. Surv. Pennsylvania*, 1876, Fayette and Westmoreland Districts.

[2] M. R. Campbell, *Masonville-Unionville Folio*, U.S. Geol. Surv.

[3] Penn. Geol. Surv., *Summary Final Rept.*, 1895, Vol. III, Part 1, "Carboniferous," p. 1924.

County the peneplain rises to approximately 1,500 feet above the railroad. As the measurements were all made from the railroad, this correction for the height of the Kittatinny base-level above it should be subtracted from the total height of the folds. Here then are two corrections of opposite sorts, one positive and the other negative. While the figure for the positive correction would seem likely to be somewhat in excess of the figure to be subtracted, there is no good basis for close figuring, and the safest thing, on the whole, seems to be to allow the present height of the peneplain above the railroad which served as a base-line for collecting the data and constructing the cross-section, to offset what younger strata there may have been above the Pottsville conglomerate. Measuring then from the railroad-level, at which the data were collected, to the top of the Pottsville should give, perhaps, as good an approximation to the height of the original folds as a similar measurement from the Kittatinny peneplain to the more uncertain upper surface of the Upper Barren Measures. These more convenient and readily available measuring-points will therefore be taken.

If, however, one should prefer to strike a general average for the thickness of these measures over the various neighboring areas where they now occur, and to assume that this full thickness of strata covered the whole extent of the Tyrone-Harrisburg section, he may readily do so. From the data given by Stevenson,[1] a figure of 1,700–1,800 feet would seem a fair one to adopt. If 1,100 feet represents the average difference in altitude between the Pennsylvania Railroad and the Kittatinny base-level, there remain, following this assumption, 600–700 feet to be added to the estimate of the height of the folded tract to be made shortly. But it is not at all certain that this full thickness of post-Pottsville sediments once extended completely over this area, and, in addition, it would seem that the thicknesses of the various Paleozoics in the reconstructed sections are more likely to be overestimates than underestimates. Because of a suspicion that possibly somewhat excessive thicknesses may have been allowed for some of the restored formations in the section, the writer prefers not to add this last correction to the total height of the folded belt.

[1] J. J. Stevenson, "Carboniferous of the Appalachian Basin," *Bull. Geol. Soc. Amer.*, Vol. XVII, pp. 65–228, and Vol. XVIII, pp. 29–178.

To determine their average vertical dimension, the cross-sections were photographed and the glazed-paper prints carefully cut at the railroad-level as base-line, and the top of the Pottsville conglomerate as the sky-line, and the resulting paper equivalents of the sections then weighed on delicate balances. At the same time similar strips of duplicate prints, cut to represent a uniform height of one mile of strata above the base-line, were also weighed. Thus weighed in the five separate sections, the results were:

	Grams
Section 1 weighed	0.4819
Scale representing same area weighed, per mile of height	0.1394
Hence average height of reconstructed beds of Section 1 is 0.4819/0.1394=3.45 miles.	
Section 2 weighed	0.4346
Scale representing strata uniformly 1 mile thick for this distance weighed	0.1833
Hence average height of reconstructed beds of Section 2 is 0.4346/0.1833=2.37 miles.	
Section 3 weighed	0.4231
Scale representing 1 mile of strata over this area weighed	0.1466
Hence average height of reconstructed beds of Section 3 is 0.4231/0.1466=2.88 miles.	
Section 4 weighed	0.3981
Scale for this distance weighed	0.1466
Hence average height of reconstructed beds of Section 4 is 0.3981/0.1466=2.71 miles.	
Section 5 weighed	0.5402
Scale for this distance weighed	0.1466
Hence average height of reconstructed beds of Section 5 is 0.5402/0.1466=3.68 miles.	

The general average height of the strata over the last four sections can be obtained directly by dividing the sum of the weights of the four paper sections by the total weight per mile of elevation of the corresponding scales.

	Grams
Total weight of Sections 2, 3, 4, and 5	1.7960
Total weight of corresponding unit mile scales	0.6231
Average height for these sections, 2.88 miles.	

Section 1 cannot be averaged in thus, as it was photographed on a slightly different scale. But the length of Section 1 on the original

plat is 1,139 millimeters, while the total length of the other four sections is 3,910 millimeters.

Therefore $\frac{(3.45 \times 1139)+(2.88 \times 3910)}{1139+3910}=3.01$ miles, the average height of the top of the restored Pottsville conglomerate over the area from Tyrone to Harrisburg.

This figure of 3 miles applies to the whole distance plotted. For the purpose of study it was also desirable to know the average height of the folded tract for the section from Tyrone only to the Catskill-Chemung contact just southeast of Marysville. The photo print of Section 5 was therefore carefully cut at this point and the northwestern portion placed on the balance. This portion weighed 0.2100 grams, while Section 5 originally weighed 0.5402 grams. This northwestern portion of Section 5 measured 559 millimeters on the large plot compared with 921 millimeters linear measurement for the whole of Section 5. Calculated on this basis the average original height of the Pottsville conglomerate from Tyrone to Marysville comes out 2.80 miles.

THICKNESS OF THE FOLDED SHELL

If one knows the average height to which the freshly folded tract was elevated, together with the amount of lateral shortening which has caused this elevation, it is a simple matter to calculate the thickness of the shell which suffered folding, neglecting compression, etc. By using the figures just obtained—81 miles compressed into 66 miles with a resulting mean elevation of 3 miles—one might make an estimate of the average thickness of corrugated strata across the whole tract. But as the thickness of the wrinkled shell is liable to be variable, it is necessary, in order to ascertain the true significance of the thickness and its variability, to consider separately the several dissimilar parts which make up the section. The most elevated tracts were on the flanks of the mountain-belt, at the two ends of the section under consideration. In both of these the Trenton limestone comes to the surface at the present time. Between these two greatest upthrusts is a long tract of lesser elevation and less acute folding. To bring out the significance of these variations, the six sections into which the whole cross-section was cut will each be considered separately.

Section 1, comprising the great anticlinal east of Tyrone, was shortened from 17.8 miles to 14.9 miles, while the top of the Pottsville conglomerate was raised to a mean height of 3.45 miles. To produce this relation between shortening and elevation, a thickness of crust amounting to 17.7 miles must have been compressed, provided there were no increase in the density of the rocks.[1]

Section 2 was found to have been shortened from 16.3 miles to 15.2 miles. As this block was raised 2.37 miles on the average by this folding, it must have had an original thickness of approximately 32.7 miles, on the assumption, of course, that the same degree of shortening persisted throughout the whole block.

Section 3 appears to have been reduced horizontally from 13.56 miles to 12.1 miles, and to have been elevated 2.88 miles. The same method of computation would assign to this block a thickness of 23.8 miles.

Section 4, which is now 12.1 miles in length, seems to have covered originally 14.44 miles. Having been upthrust to the extent of 2.71 miles, it should have a depth of 14.0 miles.

Section 5*a*, shortened from 9.6 into 7.37 miles and upthrust 2.36 miles, should constitute a block extending 7.8 miles below the measuring base.

Section 5*b*, the Cumberland County upswelling between the Susquehanna bridge and Harrisburg, rose to the extent of about 5.75 miles. I have assumed a shortening of two into one, or 9.5 miles reduced to 4.75 miles of horizontal distance. On this basis the thickness of the crust required would be only 5.75 miles, assuming uniform shortening throughout this thickness. If a greater amount of lateral compression be taken, the thickness of shell required becomes correspondingly diminished. Claypole, it will be remembered, assumed a shortening from 6 to 1 for the whole of the Cumberland Valley. On this assumption, provided the height of the folds remained the same, only about one mile of strata would need to be compressed to give the results.

[1] This method of dealing with the folded block takes no account, either of the possible increase in the density of the crumpled rocks, or of the possibility that there may have been some relief from the strains by down-folding as well as up-folding. But any changes in density must be slight, and any considerable down-folding against the great resistance of the underlying rocks seems improbable.

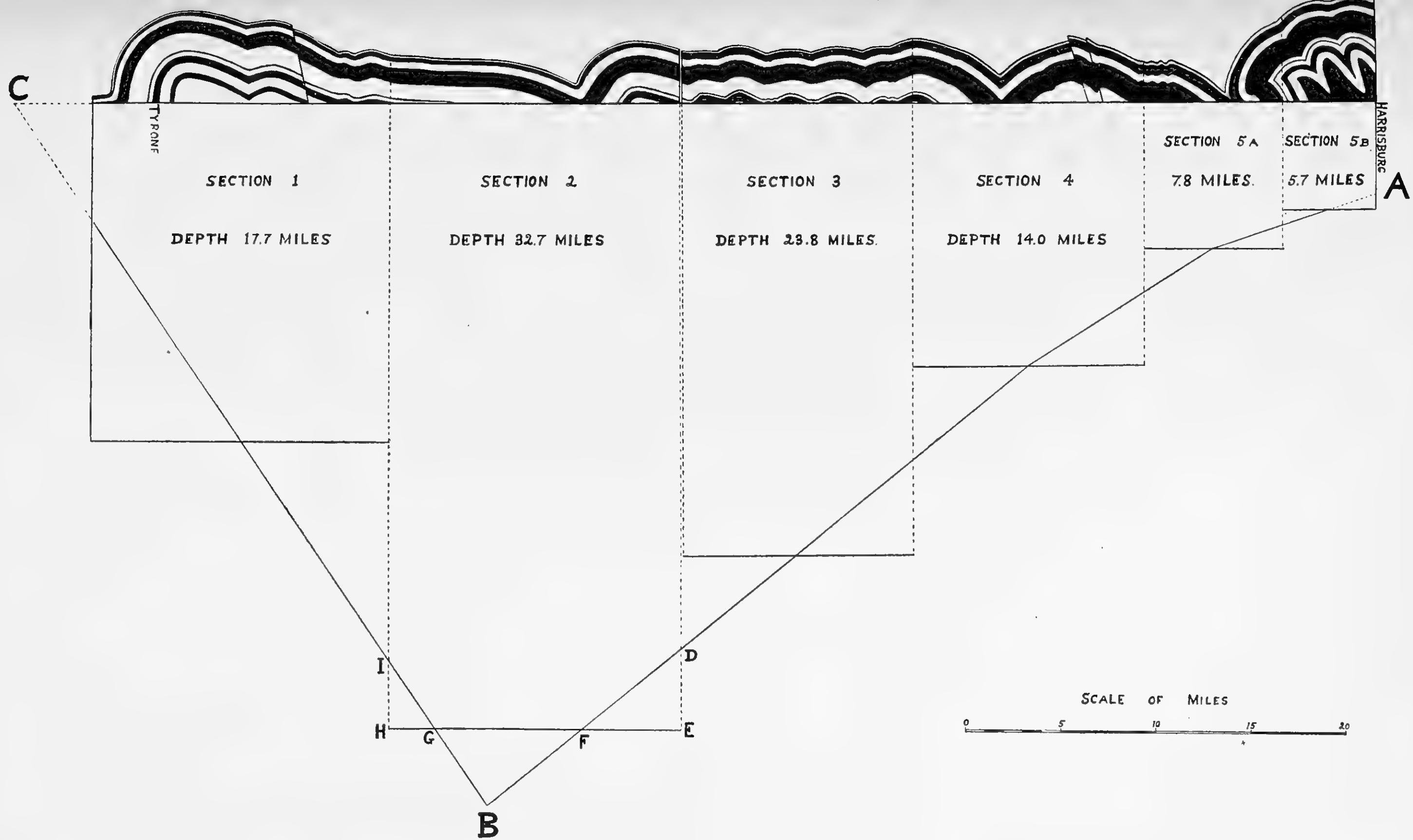

FIG. 6.—Plot of the Tyrone-Harrisburg folded section representing the thickness of deformed shell beneath each of the six blocks as developed by the above methods of measurement. The lines AB and BC are drawn through the middle points of the bottom lines of each of these blocks, except Section 2, the apex block. The triangle GBF is drawn equal in area to the sum of the triangles GHI and DEF. The whole deformed mass appears, subject to the necessary limitations, to be the triangular block ABC.

NATURE OF THE DEFORMED BLOCK

Fig. 6 expresses diagrammatically the variable thickness of the shell beneath the different sections of the folded tract, as developed by this method of analysis. The separate sections are each drawn to true scale as independent blocks, and constitute a series of steps. As the diagram rather strikingly shows, the folded shell is thinnest at the eastern end of the section and thence thickens step by step westward up to a certain turning-point, beyond which it shallows even more quickly. The regularity of these descending steps, when first worked out, came as a distinct surprise as it was not anticipated from the simple inspection of the reconstructed cross-section. It seems to be a feature of much significance and appears to give a concrete picture of how the deformation occurred.

In order to approximate more closely what may be supposed to have been the actual nature of the deformation, the broken lines *AB* and *BC* are drawn as substitutes for the artificial steps. These pass through the middle points of the bottom lines of each block with the exception of Section 2, the deepest segment, and hence the resulting sectional area of each segment remains essentially as it was in the rectangular block. Segment 2 is the apex, and to keep its area the same as the original block, the triangle *FBG* is constructed so as to equal in area the sum of the triangles *DEF* and *GHI*. At the same time Segments 1 and 3 retain their original areas.

Taken together the stepping-blocks from which the lines *AB* and *BC* have been derived are very suggestive. The thrust which produced these great mountain-flexures came presumably from the direction of the Atlantic Ocean. The near-by eastern side of the folded tract suffered more intense crumpling than the more remote western portion, the sharpest folding lying in the tract east of the present Blue Ridge. West of this the surface folds slowly die out with, however, one great fold at the west end. Simultaneously with the diminishing intensity of the folds, the thickness of the folded shell increases. Apparently the thrust from the Atlantic Ocean affected at first a moderately thin crust of five or six miles, or perhaps even less, which it squeezed intensely. From this thin, intensely compressed strip the lateral thrust was transmitted to the region lying immediately west; but instead of being communicated simply to the

upper five or six miles of strata, the strains appear to have diverged into an increasingly thick shell. In other words, the shear plane plunged downward. After reaching the maximum depth beneath Section 2, the limit of the deformed mass was deflected rapidly toward the surface. The deformed block thus assumed, in a general way, the form of a triangular prism.

That the analysis of field data should develop a deformed block of this shape and attitude was wholly unexpected but behavior of this sort is, in reality, entirely in accord with what the principles of mechanics imply for such bodies under lateral stress. In solid bodies under direct pressure, fracturing and shearing usually take place along the planes of greatest tangential stress. Becker has developed the application of this principle mathematically in the case of strained rocks. "A direct, uniformly distributed pressure of sufficient intensity, applied to an elastic brittle mass presenting great resistance to deformation, would induce fracture. The ruptures would take place along those lines subject to the greatest tangential strain, since these are the directions in which material would first be strained beyond endurance. These lines would stand at 45° to the line of force if the mass presented infinite resistance to deformation."[1] Hoskins in his analysis of strain and stress applied to the flow and fracture of rocks has also discussed this principle: "Simple sliding at any instance takes place along two sets of planes at right angles to each other and inclined 45° to the directions of elongation and shortening at that instant."[2] Leith's doctrine of fracture-cleavage is dependent upon the same principle and he agrees with Becker on the fundamental principle involved: "If fractures occur in irrotational strains, these follow intersecting planes approximately 45° to the greatest pressure—planes of greatest tangential stress."[3] The exact angle, however, varies somewhat with the nature of the substance and with the stress-conditions. In the Appalachians the greatest mountain-building pressure acted essentially horizontally. The planes of greatest tangential stress should, therefore, dip at angles somewhere in the

[1] G. F. Becker, "Finite Homogeneous Strain, Flow and Rupture of Rocks," *Bull. Geol. Soc. Amer.*, Vol. IV (1893), p. 50.

[2] L. M. Hoskins, "Flow and Fracture of Rocks as Related to Structure," *Sixteenth Ann. Rept. U.S. Geol. Surv.* (1894–95), Pt. I, p. 865.

[3] C. K. Leith, "Rock Cleavage," *Bull. 239, U.S. Geol. Surv.* (1905), p. 121.

neighborhood of 45°, and may plunge downward or upward. Whatever fracturing or shearing there be, resulting from these lateral mountain-building thrusts, should follow these dipping-planes as lines of least resistance. If the mass under stress be prevented from undergoing relative motion in these directions, a much greater force would be necessary to compel it to move in any other direction.[1]

Perfectly in accord with these deductions and bearing directly upon the case under analysis, is the experimental work of Daubrée

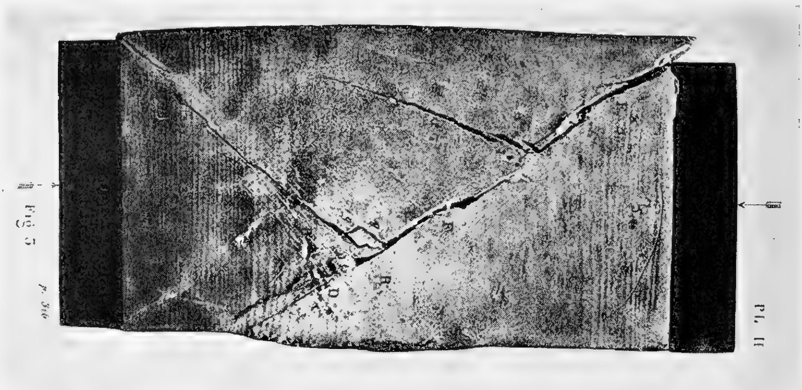

Fig. 7.—An experiment by Daubrée. The material of this prism was a carefully prepared mixture of plaster, wax, and resin, molded so as to be as nearly homogeneous as possible. When subjected to direct pressure at both ends, a wedge-shaped mass was fractured loose and lifted slightly out of its bed. Several systems of fractures have developed.

upon the problem of jointing. This brilliant experimenter subjected blocks of wax to direct pressure operating on the two opposite sides of the block. There were developed in this way two systems of fractures which were inclined to the direction of pressure at angles approximating 45°, and which, at the same time, bear a most striking resemblance to the Appalachian Mountain block *ABC* developed in Fig. 6. Fig. 7 is copied directly from one of Daubrée's plates.[2] The two figures form an instructive comparison; the one, developed from an analysis of data collected in the field without forecast of the result; the other, a photographic record of a direct experiment. In

[1] G. F. Becker, *op. cit.*, p. 47.

[2] A. Daubrée, *Etudes synthétiques de géologie expérimentale*, T. I, p. 316, Plate II, Fig. 3.

Daubrée's experiment a triangular prismatic mass has been fractured from the main block, and somewhat lifted. That it did not fold was no doubt due to the absence of adequate gravitative pressure. In the case of the earth-block the gravitative pressures at less than the block-depths exceeded the folding-strength of the strata and the wedge-shaped block deformed instead of simply rising *en masse*.

Both theoretical considerations and Daubrée's experiments show that angles of fracturing and shearing vary through a rather wide range, especially as the character of the material varies, and the correspondence of the Appalachian block to theory is perhaps closer than might be expected. In Fig. 6 the line *AB* in its deeper portion dips northwest at about 40°, while *BC*, as it is drawn, dips 54° southeast. In theory the fracture-dips in the upper horizons should normally be lower than 45° while the shear-dip in the lower, less brittle horizons, should be higher than 45°, and this seems to be exemplified in Fig. 6 and would no doubt be more strongly shown if the deformation had gone farther.

As previously stated, the greatest folds in this Pennsylvanian section lie at the two ends. The computed section in depth shows that these end portions are the thinnest and hence most susceptible to folding. The central portion descends far below the fracture-zone—and perhaps below the zone of typical folding—into the zone of quasi-flowage or plastic deformation, and this no doubt modifies the surface-deformation of this part.

At the western end the Tyrone fold seems to have been on the eve of passing into a fault when the movement ceased. Farther south faults of considerable throw have actually occurred in like positions at the inland border of the folded tract. In some parts of Tennessee the deformed belt is abruptly terminated on its western side by a sharp thrust-fault beyond which rest undisturbed horizontal beds.[1] The shell seems here to have been broken by a thrust analogous to that along *BC* in Fig. 6, and the deformed block thrust outward along the shearing-plane. The undisturbed strata lying just west of the fault indicate that the portion of the shell just outside of the disturbed block, on the west side, has not participated in the deformation. The deep plunge of the shear-plane near the western limit of the

[1] Briceville, *Tenn. Folio*, U.S. Geol. Surv

folded belt suggests that this deep insetting may constitute the mode by which the moving shell anchors itself in the less moving mass below and thus determines where the movement shall cease and the folding shall take place. This function I think is usually assigned to some specially stable portion of the earth-body. The plunge is here correlated with thick sedimentation and this may be an agency in inducing the plunge. If other cases shall support this suggestion it may offer a new view of the well-known relation between thick sedimentation and mountain-folding.

In Fig. 6 the line *BC* does not pass through the point where the strata were being shaped preparatory to faulting. This may be due to inaccuracies in the field work and in the reconstructed section. But Daubrée's experiment showed that there may be fracturing along several closely parallel lines near the edge of the moved block and that these may be broadly included in the accommodation zone. The angle *ABC* at the apex of the block is not far from a right angle. The fact that it is slightly less than 90° may be due perhaps to the fact that the triangular block has been laterally compressed, which would lessen the original angle at the apex, but such an explanation is not required as the variations of the angle natural to the case more than cover the departure from a right angle.

The likelihood of a zone of accommodation between the folded shell and the less movable interior where deformation by flowage is presumed to be the prevalent type, has been brought out in Chamberlin and Salisbury's *Geology*.[1] Near Harrisburg the moderately thin movable shell seems to have been so sharply crumpled that the adjustment between it and the solid support beneath would seem to have been accompanied by much shearing. But west of the Blue Ridge, where the folding was less intense and the compression was distributed through a much thicker segment, the adjustment between the more movable portion above and the less movable portion below may have been accomplished mainly by distributive shear. The flexures on the surface presumably pass downward into the zone of quasi-flowage where they accommodated themselves by distributive deformation.

Turning back from these details to the general problem of estimating the thickness of the folded shell, it may be recalled that the calculation commences with three dimensions obtained from the field

[1] Vol. II, p. 130.

studies, viz.: (1) the present horizontal distance across the folded section, (2) the original length of the same block before folding, and (3) the estimated average height to which the folded beds were thrust. Obviously the nature of the result obtained by this method of inspection is dependent upon the relation between the amount of crustal shortening and the height to which the beds have been raised in consequence of this shortening. Clearly, the greater the horizontal shortening of the folded block in proportion to the resulting vertical bulge, the thinner that block must be; and likewise, the less the horizontal shortening in proportion to the average height of upwarped beds, the thicker the deformed shell must be. In the Pennsylvania section considered, the less closely folded strata between the Blue Ridge and the western anticlinorium stood considerably higher in proportion to the amount of lateral shortening suffered than did the intensely folded beds to the east. Because of this, the calculations indicate a deformed shell increasing in depth to the maximum point beneath the slightly deformed region in Section 2 and thinning again beneath the anticline at the west end. These calculations, of course, assume that the folds have derived their height solely from the upthrusts of the crumpling process, and that the height of each particular area has been determined by the extent of the plication directly beneath it. If these assumptions are at variance with the facts, the conclusions are correspondingly at fault. The results, however, seem to imply that the assumptions are not seriously at fault.

For the sake of simplicity, it has been assumed that in these shortened blocks the amount of shortening deduced from the present surface beds has continued undiminished throughout the whole thickness of each block. But such uniformity is not to be expected since the thrusts of the upper and lower parts of the shell are probably not always the same and one mode of deformation doubtless grades into another. This complicating factor must lessen somewhat the significance of the numerical figures obtained, without however detracting seriously from the general nature of the results.

So far as a single test may go in justifying a method of inquiry, this trial of the suggested mode of determining the thickness of the shell involved in mountain-folding may be regarded as not only sustaining the value of the method, but as indicating forms of application whose values were not anticipated.

THE EVIDENCE OF THE FLORA REGARDING THE AGE OF THE RARITAN FORMATION

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Since it has been supposed by some invertebrate paleontologists that the Atlantic and Eastern Gulf Cretaceous above the Patapsco formation of the Maryland-Virginia area is all of post-Colorado age, i.e., Senonian by European standards, and since the faunas are for the most part poorly preserved and but partially studied, and furthermore since the physical conditions were more uniform than in the great plains area as indicated by the character of the sediments and strongly emphasized by the faunas, the following conclusions based upon a critical study of the Raritan flora may prove of interest to geologists since they clearly indicate that this flora when judged by European standards cannot be considered younger than the Turonian, while a strong case can be made out for its Cenomanian age. Furthermore when judged by American standards it is most decidedly pre-Montana in character.

No attempt is made to make the following brief article polemical in character, and hence arguments which might be drawn from stratigraphy and paleozoölogy are not mentioned, it being the desire of the writer to place a brief statement of the paleobotanical evidence before the public.

The following pages form part of a systematic report on the flora of the Raritan formation in New Jersey prepared over a year ago and to be published by the Geological Survey of that state, and the writer is indebted to the kindness of Dr. Henry B. Kümmel, the state geologist, for permission to publish them in advance of the complete report.

Passing over the somewhat diverse views of the older writers who were inclined to regard the Raritan as of Jurassic age,[1] we find Professor

[1] This age was also claimed for it by the late Professor O. C. Marsh in several papers published a score of years ago.

J. S. Newberry, in 1890, recognizing the Amboy Clays as Cenomanian in age and synchronous with the Dakota Group of the West. Professor Lester F. Ward was the first to point out that the Raritan was older than the Dakota Group, which is undoubtedly the case, and it has been customary in recent years to follow the latter author and regard the former as roughly corresponding to the Gault of England and the Albian of continental Europe. The view here presented is that the Raritan flora is much more closely allied with the Cenomanian of the Old World than it is with the Albian or Gault. At the same time it is quite obviously older than the Magothy flora, that of the Dakota Group, and those of the South Atlantic Coastal Plain,[1] so that if these latter are to be considered of Cenomanian age they are to be regarded as Upper Cenomanian while the Raritan is to be regarded as Lower Cenomanian. European geology furnishes a similar case in the division of the Cenomanian into the substages Rotomagian and Caretonian, although probably the parallelism of substages cannot be carried across the ocean. European paleontology furnishes abundant and well-characterized Cenomanian and Senonian floras for comparison and by this standard the Raritan as well as the somewhat younger Dakota and Magothy floras are clearly Cenomanian floras. The Turonian stage of European geology on the other hand has thus far yielded so meager a flora that it is practically useless as a basis for comparison and it may well be that the flora of the Dakota Group along with its southern and eastern representatives—the Woodbine, Tuscaloosa, Eutaw, Black Creek, Middendorf, and Magothy floras—represents the Turonian stage of Europe. Stratigraphically there is no contrary evidence and the Dakota sandstone would simple go with the overlying Benton which invertebrate paleontologists have long considered as representing the Turonian.

The paleobotanical evidence for the Cenomanian age of the Raritan formation is briefly as follows. On general grounds we find the Raritan flora more complex and modern in its composition than any known Albian flora; for example, dicotyledons make up 68 per cent. of the Raritan flora while not a single dicotyledon is known from the English Gault and the representation of this group of plants in the

[1] Older Cretaceous deposits are known from North Carolina to Alabama, but these are, so far as known, unfossiliferous.

Albian of France and Portugal is very meager indeed and comparable to the display of these plants in the Patapsco formation of Maryland and Virginia, the latter showing a striking parallelism with the Albian of the Old World with at least one identical species and closely allied representatives in several identical genera.

Species which are peculiar to the Raritan formation number 51 as follows:

Acer amboyense Newb.
Aralia patens Holl.
Aralia rotundiloba Newb.
Asplenium raritanensis Berry
Bauhinia gigantea Newb.
Caesalpinia cookiana Holl.
Caesalpinia raritanensis Berry
Calycites diospyriformis Newb.
Calycites parvus Newb.
Carpolithus ovaeformis Newb.
Carpolithus pruniformis Newb.
Carpolithus woodbridgensis Newb.
Celastrophyllum grandifolium Newb.
Celastrophyllum minus Holl.
Celastrophyllum spatulatum Newb.
Chondrites flexuosus Newb.
Chondrophyllum obovatum Newb.
Chondrophyllum reticulatum Newb.
Cornophyllum vetustum Newb.
Dewalquea trifoliata Newb.
Diospyros raritanensis Berry
Eucalyptus parvifolia Newb.
Fontainea grandifolia Newb.
Hedera obliqua Newb.
Ilex elongata Newb.
Ilex amboyensis Berry
Laurophyllum lanceolatum Newb.
Laurophyllum minus Newb.
Leguminosites raritanensis Berry
Liriodendron quercifolium Newb.
Menspermites wardianus Holl.
Myrica acuta Holl.
Myrica cinnamomifolia Newb.
Myrica fenestrata Newb.
Myrica hollicki Ward
Myrica Newberryana Holl.
Myrica raritanensis Holl.
Myrsine oblongata Holl.
Newberryana rigida (N.) Berry
Passiflora antiqua Newb.
Phyllites undulátus Newb.
Planera knowltoniana Holl.
Persoonia spatulata Holl.
Podozamites acuminatus Holl.
Populus orbicularis (Newb.) Berry
Protophyllum obovatum Newb.
Prunus (?) acutifolia Newb.
Rhamnites minor Holl.
Salix pseudo-hayei Berry
Sphaerites raritanensis Berry
Williamsonia smockii Newb.

Obviously these are of little service in correlation; nevertheless all but one or two are dicotyledons of genera which in Europe are found in the Cenomanian, Turonian, and Senonian. Allied forms are largely represented in the Magothy formation, the Dakota Group, and the Atane beds of Greenland.

There are eleven Lower Cretaceous species which persist into the Raritan. These are:

Asplenium dicksonianum Heer
Celastrophyllum brittonianum Hollick
Ficus myricoides Hollick
Frenelopsis hoheneggeri (Ettings.) Schenk
Gleichenia giesekiana Heer
Gleichenia micromera Heer
Gleichenia zippei Heer
Podozamites knowltoni Berry
Podozamites lanceolatus (L. & H.) F. Braun
Sequoia reichenbachi (Gein.) Heer
Thuyites meriani Heer

Of these the ferns and the gymnosperms which make up the bulk of the list are to be regarded primarily as Lower Cretaceous types which survived into the Upper Cretaceous, while the dicotyledons are precursors of the Upper Cretaceous flora. Among the generic types of ancient lineage which are represented in the Raritan are Baiera, primarily a Triassic and Jurassic genus the Raritan species of which is closely related to forms found in the Older Potomac, Williamsonia, a Jurassic and Lower Cretaceous genus, Brachyphyllum, a Triassic and Jurassic genus the Raritan species of which is closely related to, and clearly descended from, *Brachyphyllum crassicaule* Font. of the Patapsco formation, and finally Czekanowskia, a Triassic and Jurassic (chiefly Oölitic) genus.

In no part of the world has a single representative of any of these genera been found as late as the Senonian and it is significant that two of them, Brachyphyllum[1] and Czekanowskia, furnish their last known record in the Cenomanian of Portugal while the last occurrence of Baiera and Williamsonia[2] is in the Cenomanian Atane beds of Greenland.

When the Raritan flora is compared in detail with the Patapsco flora of Maryland and Virginia many common features are brought out which at first sight tend to be obscured by the preponderating dicotyledonous element in the former. In addition to the identical or closely related forms previously mentioned we find among the dicotyledons nine Raritan genera which make their first appearance in the Patapsco. These are Aralia, Sassafras, Celastrophyllum,

[1] The Raritan species *B. macrocarpum* Newb. is recorded from the following American horizons: Montana Group of Wyoming, Dakota Group of Kansas, Magothy formation of Long Island, New Jersey, and Delaware, the Middendorf of South Carolina (?), the Black Creek of North Carolina, the Tuscaloosa and Eutaw of Alabama, and the Patoot beds of Greenland (?), the former of course of Senonian age.

[2] A questionable species is recorded from the Dakota Group and another species occurs in the Magothy formation.

Cissites, Sterculia, Quercus, Populus, Eucalyptus, and Ficus. The genus Celastrophyllum with a large display of forms in both the Patapsco and the Raritan has one identical species, *C. brittonianum* Hollick, while *C. hunteri* of the former is very close and ancestral if not actually identical with *C. angustifolium* Newb. of the latter. Eucalyptus has closely related species at both horizons while Ficus has a common species, *F. myricoides* Hollick, in both formations.

Among the conifers the widespread *Widdringtonites ramosus* (Font.) Berry of the Patapsco is closely related to, if not identical with, the equally common *Widdringtonites reichii* (Ettings.) Heer of the Raritan and succeeding formations. The genus Frenelopsis has closely related species in both while Sequoia and Thuyites have already been mentioned as well as the cycadean genus Podozamites which ranges back to the Triassic. Two Raritan species are recorded from the European Albian. These are *Sequoia reichenbachi* (Gein.) Heer and *Eucalyptus angusta* Velen., the former a very wide-ranging form and the latter recorded from the Albian of Portugal and the Cenomanian of Bohemia.

Turning to the elements in the Raritan flora which ally it with younger floras, we find that six of the Raritan species persist as late as the Senonian of Europe and fifteen are found in the Patoot beds of Greenland which are also usually regarded as of Senonian age. All but four of the latter are, however, found in the Cenomanian beds of that country and practically all of the others and those common to the Senonian of Europe as well occur somewhere in Cenomanian strata. There are thirty-four species common to the Raritan flora and that of the Dakota Group,[1] the former lacking more particularly the numerous forms of Betula, Quercus, Platanus, etc., which characterize the latter. There are 32 species common to the Raritan and to the Atane beds of Greenland, the latter formation being usually regarded as Cenomanian in age, and there are sixty-seven species common to the Raritan and Magothy floras, although these latter figures are somewhat obscured by the difficulty of determining the probable age of many of the species recorded from Long Island and other areas in the vicinity of the terminal moraine and by the additional

[1] This statement applies only to New Jersey forms and is intensified if the supposed Raritan of Staten Island and Long Island is included.

fact that the Upper Raritan at South Amboy, N.J., furnished many of these identical species and it is quite likely that some of the species credited to South Amboy on the authority of Professor Newberry and not since collected may really have come from within the Magothy formation, since the Morgan locality which is of Magothy age would not have been kept distinct from South Amboy as a place-name in Professor Newberry's day.

The known Montana Group flora, the published accounts of which, by Dr. F. H. Knowlton, are contained in *Bulletins 163* and *257* of the U.S. Geological Survey, embraces over one hundred species of which six are common to earlier horizons, two to the flora of the Dakota Group, and five to that of the Raritan, all being pre-Senonian survivors. One of these, *Sequoia reichenbachi*, ranges from the base to the summit of the Cretaceous and hence possesses no significance, and another, *Sequoia heterophylla*, ranges up into the Senonian of Europe. On the other hand not one of the characteristic Senonian (Montana) species occurs in the Raritan and there are twenty-seven Montana genera which are not even represented in the Raritan flora. Not one of the eleven Lower Cretaceous species which persist into the Raritan of the East are found in the Montana flora, although similar Lower Cretaceous floras are known from the Trinity of Texas, the Kootanie of Montana and Canada, the Lakota of the Black Hills, and the Shasta of California. If they survive in the East until Montana time, as has been asserted, why not at some other point on the earth's surface where conditions must have been equally favorable? Furthermore, the characteristic genera of the Raritan flora, such as Aralia, Sassafras, Celastrophyllum, Eucalyptus, Sterculia, Cissites, etc., are entirely unrepresented in the Montana flora, which has a totally different and more modern facies and the genera which are common to the two horizons, such as Myrica, Magnolia, Ficus, etc., have an entirely different set of species.

In conclusion it should be pointed out that the Raritan flora as developed in New Jersey includes over 150 species which are for the most part well preserved and abundantly represented. In striking contrast with this representative flora the supposed Raritan fauna comprises a species of Astarte, one of Ambocardia, one of Rangia (?), two of Corbicula, one of Corbula, one of Turritella, and one of Cym-

bophora, the two latter marine and specifically unidentifiable and the six former brackish in type and of doubtful generic relations.[1]

Dr. Stuart Weller in his admirable investigation of the New Jersey Cretaceous did not actually collect any of these forms and all are based on single occurrences mostly of ancient date made when the importance of definiteness regarding exact localities was not appreciated. None have been subsequently collected, although the number of openings in this area is very great; the region is visited annually by numerous geological students and it is a common practice for the workmen to save unusual objects such as fossils which they find and these usually find their way into the hands of collectors visiting the clay-pits.

The Astarte is listed on the authority of Conrad, the Ambocardia, Rangia, and the two Corbiculas on the authority of Whitfield, and the Turritella and Cymbophora on the evidence of a single slab of sandstone in the State Survey collection obtained over twenty-five years ago and said to have come from Sayreville. It will be obvious that evidence of so scanty and indecisive a character is hardly to be given much weight.

CONCLUSIONS

1. The Raritan flora is clearly shown to be of Upper Cretaceous age.

2. It is shown to be very similar to, but somewhat older than, the flora of the Dakota Group, and to be identical with widely scattered floras usually regarded as of Cenomanian age.

3. It is shown to be totally distinct from the known flora of the Montana Group.

[1] Weller, *Geol. Surv. of N.J., Paleont.*, IV (1907), 28.

THE SECONDARY STRUCTURES OF THE EASTERN PART OF THE BARABOO QUARTZITE RANGE, WISCONSIN

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CONTENTS

INTRODUCTION

Despite the many valuable investigations on secondary structures from theoretical, experimental, and field viewpoints, practically no systematic attempt has been made to correlate secondary structures with stress strain relations which have given rise to major units of structure over large areas. The value of such investigations is being forced home, particularly in areas of poor exposure, where a few scattered details regarding the secondary structures are sometimes the only key to the major structure of industrially important areas.

PURPOSE AND SCOPE OF THE INVESTIGATION

This paper aims to set forth the relation of the joints and other secondary structures of the well-known and well-exposed eastern portion of the Baraboo quartzite range, to the stress strain relations which have developed the structural units of which the district is a whole or a part. On this basis the secondary structures of the district have been classified as those (1) related to the folding of the range, and (2) those not related to the folding of the range.

The[1] Baraboo quartzite district consists of an asymmetrical synclinical fold of pre-Cambrian formations, striking a little north of east and west, with a steep north limb and a gently dipping south limb. (See Fig. 2 of north-and-south section.) The succession from the base up is igneous rock, unconformity, quartzite, slate, iron formation, and dolomite. The only exposures are those of igneous rocks and quartzite, the latter making a prominent ridge encircling the district. The quartzite ridge of the north limb is known as the North Range, while that of the south limb is called the South Range.

Several months were spent in the field during 1905–6 in making several thousand observations on dips and strikes of beds and secondary structures, in an area comprising 5 square miles in the vicinity of Devil's Lake and the Lower Baraboo Narrows. Since then the problem has been reviewed annually by the writer, both in the field and in the office. Both data and results have received the criticism of C. K. Leith, to whom the writer is indebted.

SECONDARY STRUCTURES RELATED TO THE FOLDING OF THE RANGE

The secondary structures in the pre-Cambrian series of the Baraboo quartzite range consist of (1) closed, interrupted joints parallel to the bedding; (2) strike joints which intersect one or more beds and offset between the beds, and constitute a series of overthrust faults of minute throw; (3) strike cleavage both parallel and diagonal to the bedding.

The abundance of the joints related to the folding is dependent upon the inclination of the beds, the distance from the contact of formations, and the strength of the beds. They are more abundant where the strata are highly tilted, than where their dip is nearly horizontal. Thus in the quartzite of the South Range, having a dip of from 5–20 degrees north and striking N. 65–75 degrees east, only about 20 per cent. of the total number of joints are related to the folding; while on the North Range, where the quartzite strikes E.–W. and is vertical or nearly vertical in dip, 40 per cent. or more of the joints are connected with the folding, and of these, the joints

[1] Samuel Weidman, "Baraboo Iron Bearing District," *Wisconsin Geological and Natural History Survey, Bulletin No. 13*, 1904.

parallel to the bedding are the more important. The diagonal strike joints of the North Range are nearly horizontal, owing to the vertical attitude of the beds.

The effect which proximity to a contact has upon the abundance of joints related to the folding is well illustrated on the South Range near Devil's Nose, where the quartzite comes in contact with the granite porphyry to the south. At this place, both bedding and

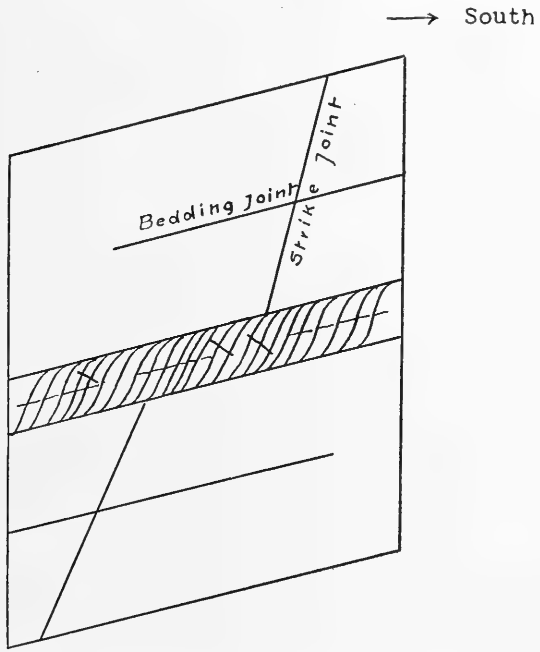

Fig. 1.—Vertical section, normal to the strike on the South Range, showing the relation of the joints connected with the folding in weak, thin beds interstratified with thick, strong beds.

strike joints are so closely spaced as to break the quartzite into a rubble. Away from this contact, the zone of intense fracturing rapidly disappears.

Strong beds have fewer joints related to the folding than weak beds. Throughout the quartzite formation, weak, thin beds of slaty quartzite are intercalated between massive, strong beds of quartzite. Near the site of the old Cliff House on the east bluff at Devil's Lake, there are two such weak beds, each about a half-

foot in thickness, separated by a thick bed of quartzite. Both bedding and diagonal strike joints are present in these beds. The beds strike N. 65 E., and dip 20 degrees north. The diagonal strike fractures are closely spaced *ƒ*-shaped fractures, which are nearly parallel to the bedding plane near the upper and lower surfaces of the bed, while at the center of the bed their dip is 50 degrees north. Some of these *ƒ*-shaped diagonal strike joints are connected with north-dipping diagonal strike joints in the strong quartzite beds. Another set of diagonal strike joints intersects the *ƒ*-shaped set. Fig. 1 shows the relation of the joints connected with the folding in thin, weak beds interstratified with strong, thick beds.

The igneous rocks both on the North and the South Range have joints related to the folding of the range. These joints strike parallel to the strike of the quartzite formation and are vertical or nearly vertical closed joints.

Locally intense dynamic activity accompanying the folding of the range has deformed the formations by flowage, resulting in the development of a schist. On the North Range, at the Lower Baraboo Narrows, in a zone about one hundred feet wide following the contact of the quartzite and the ryolite to the north, the ryolite and some of the quartzite have been rendered schistose. The strike of the cleavage conforms to the strike of the bedding of the quartzite. Its dip is vertical or nearly vertical in the quartzite. In the ryolite it varies from vertical to 65 degrees north.

SECONDARY STRUCTURES NOT RELATED TO THE FOLDING OF THE RANGE

The joints which are most conspicuous in the Baraboo quartzite formation, about 80 per cent. of the joints of the South Range, and approximately 60 per cent. of the joints of the North Range are not related to the folding of the range. Their strike and dip relations differ radically from the joints and secondary structures which are connected with the folding in that their strike and dip relations are independent of the strike and dip relations of the quartzite formation. These independent joints usually occur in sets at right angles to each other. They have considerable continuity both along the strike and the dip, and stand out as gaping, open, vertical, or nearly vertical

fissures. On the South Range, the majority of these independent joints, about 60 per cent. of the total number of joints, strike N. 60 E. and N. 30 W. Nearly 20 per cent. strike N. 20–30 W., and the remainder strike in various other directions of the compass. On the North Range, the principal directions of rupture independent of the fold are N. 30–40 E., and N. 30–40 W., and N.–S.

It has been found that some of the joints unrelated to the folding are connected with deformation of the Cambrian. Thus the predominant directions of jointing in the Cambrian of the eastern end of the quartzite range is N. 60 E. and N. 30 W., which is the predominant direction of rupture of the quartzite on the South Range. This does not preclude the possibility that this set of fissures existed in the quartzite before the deformation of the Cambrian. It has been observed repeatedly that N. 60 E., N. 30 W., N. 10 E., N. 30 E., N. 35 E., N. 50 E., N. 20 W., N. 25 W., N. 35 W., N. 60 W., N. 70 W., N. 80 W. joints are continuous through both Cambrian sandstone and pre-Cambrian quartzite. On the other hand there is abundant evidence that many joints independent of the fold existed in the quartzite before the Cambrian was deposited, since (1) these continuous vertical joints are more prominent in the quartzite than in the Cambrian; (2) the quartzite conglomerate bowlders at the base of the Cambrian are dissected by a diversity of joints, some of them cemented with quartz, many of which could not have been related to the folding, or have developed by processes connected either with the deposition or the deformation of the Cambrian; (3) the Cambrian sandstone has been deposited in wide gaping fissures of the quartzite whose directions are independent of dip and strike relations of the quartzite. Thus at Devil's Lake where the quartzite strikes N. 65–75 E., and dips from 5–25 N., a vertical fissure several feet in width, striking N. 25 W., is filled with Cambrian sandstone.

Among the secondary structures independent of the fold are a few small, vertical shear zones[1] in the quartzite on the east bluff of Devil's Lake. The largest of these strikes N. 85 W. Since the south wall of this fault is more intensely shattered than the north wall, and

[1] See illustration on p. 17, Rollin D. Salisbury, "The Geography of the Region about Devil's Lake and the Dalles of the Wisconsin," *Bulletin No. 5, Wisconsin Geological and Natural History Survey.*

shows a drag toward the south, it is concluded that the south wall has dropped with reference to the north wall. The amount of lateral or vertical displacement is not known, but these movements have very likely been small since the lateral extension of the shear zone appears to be very limited.

RÉSUMÉ OF THE SECONDARY STRUCTURES

The cleavage and a minority of the joints of the pre-Cambrian rocks exposed on the eastern end of the Baraboo quartzite range are related to the folding of the range. On the South Range, about 20 per cent. of the joints, and on the North Range, about 40 per cent. are related to the folding.

Many of the joints of the pre-Cambrian are independent of the folding, having been developed in part before the deposition of the Cambrian, and in part after the deposition of the Cambrian. About 80 per cent. of the joints of the South Range and 60 per cent. of those of the North Range are unrelated to the folding.

THE MECHANICS OF THE SECONDARY STRUCTURES OF THE EASTERN PART OF THE BARABOO QUARTZITE RANGE

It is evident from the description of the secondary structures of the Baraboo quartzite range that there are two distinct types of joints present. The joints of the predominant type, comprising about 80 per cent. of the joints of the South Range, and about 60 per cent. of the joints of the North Range, are independent in their strike, dip, and space relations of the quartzite formation. They were not produced by the folding of the range, but by later deformations. Another type of joints, comprising about 20 per cent. of the joints of the South Range, and 40 per cent. of the joints of the North Range, are connected with the folding of the range. They are the vertical and north-dipping discontinuous, diagonal strike joints, and the bedding joints of the South Range, and the bedding joints and the nearly horizontal strike joints of the North Range. The two types will be given separate attention.

THE SECONDARY STRUCTURES PRODUCED BY THE FOLDING OF THE RANGE

The folding of the quartzite formation was accomplished by slipping between the beds, by fracturing, and by the flowing of the beds.

These movements were in the direction of the anticlinal axis of the fold for an upper bed with reference to a lower bed, and in the direction of the synclinal axis for a lower bed with respect to an upper bed. More deformation took place in weak beds than in strong beds; more in highly tilted beds than in slightly tilted beds. Other factors also influenced the movement. For instance, a large amount of readjustment took place at the contact of the quartzite and the underlying igneous rocks. It may be that this was due to the absence of easy planes of slipping in the massive igneous rocks and that consequently a large part of the required amount of movement took place at the

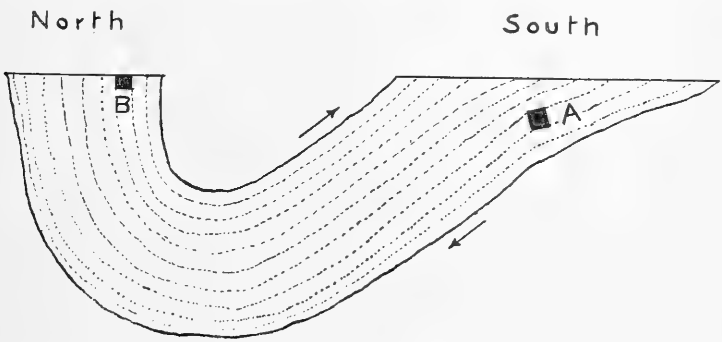

FIG. 2.—Diagrammatic north-to-south section of the quartzite formation. Scale of cross-section: $\frac{3}{4}$ inch = 1 mile. *A* and *B* represent sections of cubes in the beds before deformation.

contact of the two formations. Fig. 2 represents a diagrammatic north-to-south section of the quartzite formation. The arrows indicate the direction of movement in the beds in the process of folding. *A* and *B* represent sections of cubes in the beds before deformation. After deformation, the cubes will be deformed into parallelopipeds, and the sections *A* and *B* will be deformed into parallelograms. Spheres inscribed in the original cubes are deformed into ellipsoids called the strain ellipsoids. Fig. 3 represents *A* of Fig. 2, a vertical section of a cube normal to the strike, and the parallelogram resulting from the deformation of *A*; the circle inscribed in *A*, and the resulting ellipse of strain. Fig. 4 represents a similar section on the North Range where the bedding is vertical. The arrows indicate the direction of slipping between the beds.

The massive quartzite beds and the massive igneous rocks were deformed largely under conditions of fracture, excepting at the contact of the two formations where some of the deformation was accomplished by flow. Those rocks which were deformed under conditions of fracture ruptured as soon as the stresses exceeded the ultimate strength of the rocks. According to the best mechanical analysis, rupture which results from compression takes place along the planes of no distortion or constant area, since these are the planes of maximum tangential stress. In Figs. 3 and 4 they are represented by XY and LM. It is evident that LM is equivalent to the bedding joints,

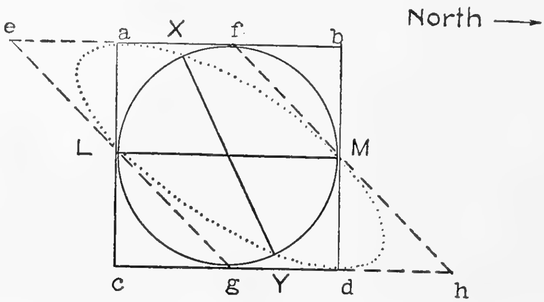

FIG. 3.—*abcd* represents A of Fig. 2; *efgh* represents the parallelogram of strain resulting from deformation; the circle inscribed in A has been deformed into an ellipse. XY and LM are the planes of no distortion or the planes of maximum tangential stress, and of rupture.

and XY is the vertical, or north-dipping strike fracture, diagonal to the bedding of the South Range, or the nearly horizontal strike fracture of the North Range, where the beds are steeply inclined. The strike fractures constitute a series of overthrust faults of minute throw, which approximately bisect the angle between the longest axis of the strain ellipsoid and a normal to the bed. The initial angle between the longest axis of the strain ellipsoid and a normal to the bed is 45 degrees. The rotation of the longest axis of the strain ellipsoid beyond the initial 45-degree position depends upon the amount of internal flow coincident in direction with the movement between the beds. Since more internal flow takes place in weak beds than in strong beds other conditions being the same, the strain ellipsoids are rotated

more in weak beds than in strong beds, and hence the diagonal strike fractures are more nearly parallel to the bedding in weak beds than in strong beds. This principle accounts for the *ʃ*-shaped fractures in the shaly layers at Devil's Lake, previously described. Near the upper and the lower surfaces of these weak beds, where internal adjustment was greatest, these fractures are more nearly parallel to the bedding than in the center of the beds, where internal adjustment was least. The stretching of the beds parallel to the longest

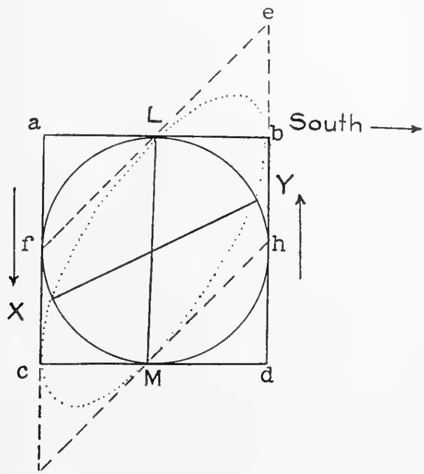

Fig. 4.—*abcd* represents *B* of Fig. 2; *efgh* represents the parallelogram of strain resulting from the deformation of *abcd*. *XY* and *LM* are the intersections of the circle inscribed in *abcd* and the strain ellipse resulting from the deformation of the circle. *XY* and *LM* are the directions of maximum tangential stress, and of rupture.

axis of the strain ellipsoid causes tension fractures to develop normal to the direction of maximum elongation. See diagonal strike fractures which intersect the *ʃ*-shaped strike fractures of Fig. 1.

The development of bedding and diagonal strike shearing joints by the folding on the north limb of the Baraboo syncline is illustrated by Chamberlin and Salisbury in *Geology*, Vol. I, p. 445, Fig. 367. The bed on the left of Fig. 367 is a weak, shaly bed stratigraphically beneath the stronger quartzite bed to the right. In the weak bed the diagonal strike fractures are closely spaced, while both bedding and nearly horizontal, diagonal strike fractures, rather widely spaced,

are visible in the stronger bed. The movement of the stronger bed has been upward with reference to the weaker bed.

The preceding analysis seems to account for all the fractures which show by their strike, dip, and other relations that they are related to the folding of the range. It is to be noted that these fractures are the result of compression rather than tension. Theoretically, it is possible that tension may have caused a set of vertical, gaping strike joints especially on the crest and trough of the fold. It is difficult to determine what part of the strike and dip joints are of this origin, but most of this class have been connected by observation with the compression joints produced by the folding of the range, and thus far no definite evidence of tension joints related to the folding has been found.

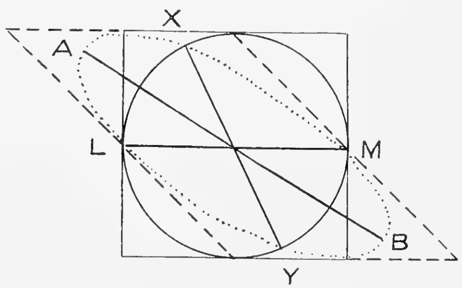

FIG. 5.—*AB*, the longest axis of the strain ellipsoid, is the direction of cleavage in a rock deformed by flow. *XY* and *LM* are the directions of rupture in a rock deformed under conditions of fracture.

Wherever deformation was accomplished largely by flow, cleavage resulted. Cleavage is the capacity of a rock to part along parallel surfaces which are determined by the orientation of the mineral particles parallel to the longer axis of the strain ellipsoid. Fig. 5 shows the strain ellipsoid and the direction of cleavage parallel to the longest axis *AB* of the strain ellipsoid as compared with the directions of maximum tangential stress or rupture *XY* and *LM*. The degree of rotation of the strain ellipsoid, and hence the inclination of the cleavage with respect to the bedding, depends upon the amount of flow. On the North Range, at the contact of the igneous rocks and the quartzite, the plane of cleavage is nearly parallel to the bedding of the quartzite. Farther to the north in the igneous rocks where flowage was less intense, the dip of the cleavage is diagonal to the inclination of the quartzite beds. The cleavage, in the granite porphyry on the South Range at Devil's Nose, is inclined to the north at a steeper angle than the overlying quartzite beds.

THE SECONDARY STRUCTURES INDEPENDENT OF THE FOLD

It is believed that the joints which are independent of the Baraboo syncline are due to tension rather than compression, since they lack strike and dip relations but are usually vertical, open, and occur in approximately rectangular sets whereas, if they were due to compression, they would occur as closed, inclined shearing joints, striking more nearly in one direction.

If the joints, which are independent of the syncline, are due to tension, then the most probable source of tensile stresses would be complex folding under conditions of moderate load. Under such conditions folding will produce rectangular sets of strike and dip joints normal to the direction of tensile stress.

From the description of the secondary structures, it follows that the Baraboo quartzite was subjected to at least one deformation after the folding and before the Cambrian was deposited, and at least one deformation after the deposition of the Cambrian. It seems that one of the principal directions of rupture caused by the deformation following the folding was N. 20–30 W., and therefore it is possible that this was one of the axial directions of this deformation. The directions of maximum rupture in the Cambrian are N. 60 E. and N. 30 W., and therefore assuming that these joints are due to tension caused by complex folding, the axes of the Cambrian fold are approximately N. 60 E., and N. 30 W., in the district. The intermediate systems may have originated with the preceding systems of independent joints, or they may have developed through other stresses.

CONCLUSION

About 20 per cent. of the joints of the South Range, and 40 per cent. of the joints of the North Range are compressive shearing joints developed in planes parallel to the bedding, and in planes parallel to the strike and diagonal to the bedding by strains developed during the formation of the Baraboo syncline. A part of the joints so classed may be due to tension, but there is no direct evidence of this.

The remaining joints, constituting about 80 per cent. of the joints of the South Range, and 60 per cent. of the joints of the North Range, are obviously independent of the folding of the range, having no

relation to the attitude of the bedding. Their origin is uncertain, but a large proportion of them are probably tension joints controlled by larger units of structure than Baraboo Range.

The cleavage locally developed in the rocks of the Baraboo syncline has been correlated with the folding of the range.

The results of this investigation emphasize a principle which has not often received adequate attention, that the secondary structures are parts of larger structures, that these in turn are parts of still larger structures, and that therefore the secondary structures may be the key to the major structure. Description of joints, fractures, cleavage, and faults, as so many isolated details, has value in the interpretation of earth history, only when it leads to the correlation of these structures with the major structures of a district.

DIABASE OF THE COBALT DISTRICT, ONTARIO

REGINALD E. HORE

Here referred to is that portion of the District of Nipissing from Lake Temagami north to the Hudson Bay watershed, an area about eighty miles square. A general description of the region has recently[1] been given by the writer, and some of the geological features are outlined in the following table.

In this area are many recently discovered deposits of native silver, the most important being at Cobalt. All the deposits are in pre-Cambrian rocks, most of the valuable ones in Huronian conglomerate, and a few in Keewatin greenstones and Keweenawan diabase. In all cases the deposits are closely associated with masses of diabase, and are probably genetically connected with them.

In the following description of the diabase, mention is also made of minor intrusions and fissure-fillings, it being suggested that all or part may have originated in the diabase magma and are an expression of the phenomena which occurred on cooling.

The diabase masses.—In almost every township there are outcrops of quartz-diabase. Many of the exposed masses are very irregular in outline, while others show decidedly elongated forms with the longer dimension generally north and south. In several instances the diabase conforms to, and apparently has had its shape determined by, the bedding planes in intruded shales; but some similar masses show in places more stocklike characters, intruding the shales at high angles and forming schistose and slaty contact zones. In rocks other than shales the diabase shows less pronounced sheetlike forms, and appears rather as small stocks and dikes.

General character of the diabase.—The greater part of the diabase masses is of gray to dark-gray color, of medium grain, and with ophitic texture. The specific gravity is about 3.00. The rock is composed chiefly of gray or greenish sodi-calcic feldspar and dull-

[1] R. E. Hore, "Silver Fields of Nipissing," Toronto meeting, Canadian Mining Institute, 1910.

brown pyroxenes. Biotite and black iron oxides are generally visible. Quartz is generally present; but often in small quantity intergrown with feldspar and not always visible to the naked eye. In some specimens there is a decided pink color due to the presence of pink feldspar, and in these portions quartz is more prominent, and grains of pyrite and chalcopyrite are frequently visible. In rarer instances the rock is almost completely made up of feldspar and quartz with but small amounts of ferromagnesian minerals. In some of the masses there are numerous small aplitic veins closely related to the quartz-feldspar portions just mentioned but practically free of ferromagnesian minerals.

Microscopic character.—Specimens of medium-grained gray diabase from all parts of the district show very similar composition. Plagioclase feldspars and pyroxenes are the only minerals present in large quantity. Iron ores are always present in small quantity, and filling the interstices is a micrographic intergrowth of feldspar and quartz.

In thin sections the fresh rock is nearly colorless. Generally the feldspar is somewhat clouded with alteration products, and the pale-brown tinted pyroxene has usually some greenish uralitic or chloritic spots. Angular particles of black ilmenite are generally partially altered to grayish-white leucoxene.

Other minerals sometimes found include biotite, hornblende, quartz, apatite, olivine, chalcopyrite, and pyrite. Among secondary minerals are chlorite, sericite, leucoxene, sphene, limonite, epidote, and carbonates.

Pyroxene.—The common pyroxene is of very pale brownish color. Rarely one finds decided violet-tinted varieties. The shape is irregular and has evidently been determined by the nature of the spaces left after most of the feldspar had crystallized. Less commonly the pyroxene and feldspar crystal boundaries are equally well developed. The size varies greatly in slices from different specimens; commonly they are from 2 to 5 mm. but some of coarser grain show blades of pyroxene from 5 to 20 mm. in length. These large crystals are usually twinned and show marked diallagic striae and they are generally somewhat altered to a greenish fibrous hornblendic substance. Some slides show numerous grains which have the optical

properties of rhombic pyroxenes; but their composition has not been definitely determined.

Feldspar.—The feldspars generally show green or gray tints and occasionally there is present a pink-colored variety. The measurement of angles of extinction by the Michel-Levy method indicates that much of the feldspar is of highly calcic varieties, and chemical analysis of the rock indicates the same. The pink-colored feldspar is more highly sodic, and in aplitic veins showing no ferromagnesian mineral has the composition of albite. The lime-soda feldspars are rarely fresh, partial alterations being indicated by white opaque portions and small grains and flakes of brightly polarizing minerals, the exact nature of which has not been definitely determined. Small grains of epidote are characteristic components of the aggregate. The sodic feldspars, unlike the calcic, are very free from evidences of decomposition.

Ilmenite occurs in typical forms showing the skeleton-like arrangement, and alteration along crystallographic directions to leucoxene. The powdered mineral is not noticeably attracted by the magnet, but large rock masses influence the magnetic needle.

Quartz occurs frequently intergrown micrographically with feldspar, and in the gray diabase is rare otherwise. In the aplitic veins it is often found with the feldspar in typical panidiomorphic structure.

Biotite occurs frequently as dark-brown pleochroic plates, which are conspicuous in the powdered rock, though their weight is comparatively insignificant.

Hornblende.—A green hornblende is a common constituent, especially in specimens which show alterations in the pyroxenes. It is usually in fibrous aggregates and is probably secondary. Some few specimens in which pyroxenes are quite fresh show well-formed green hornblende which is probably primary. A partial analysis of the red rock from James Township (Anal. 4) showed less than 1 per cent total alkalies, and as part at least of this was due to incomplete separation from feldspars, the hornblende in this sodic portion is not an alkali variety.

Olivine is typically absent in the large diabase masses but occurs as yellowish-green grains in varieties containing no micropegmatite. In small intrusives olivine is a common constituent.

Chemical composition of the diabase.—The examination of exposures in all parts of the district proves that most of the diabase is of the medium-grained gray type and the microscopic examination shows that there is great uniformity in the mineral composition of this rock. Chemical analysis of specimens from one locality may therefore be taken as typical of many square miles of the diabase. The following analyses (Nos. 1, 2, and 3) are of specimens taken from the diabase in the silver-producing area at Cobalt. All three specimens were taken a few inches from the surface and in them are evidences of alteration—especially in the feldspars. In reddish portions of the diabase, analysis (see No. 4) shows a higher percentage of silicon and a marked increase in sodium, and microscopic examination of such specimens shows a higher percentage of feldspar-quartz intergrowths and less of pyroxene.

Diabase dikes.—In the diabase there are dikes and veins of various types. The darker-colored dikes are usually very fine grained, distinctly ophitic in texture, high in content of iron oxides, and frequently show olivine. They vary in width from a few inches to several feet. Dikes more than one hundred feet wide are usually very similar in composition to the larger masses. A comparatively small number of the dark-colored dikes show little or no olivine and are characterized by large phenocrysts of white or gray plagioclase among which labradorite has been recognized.

The sodic aplitic veins.—Lighter-colored dikes and veins are in some cases composed almost entirely of sodic feldspars and quartz. Most of the other fillings have quartz or calcite as the chief mineral, and where both are present the quartz is distinctly older than the calcite. These light-colored fissure-fillings are in many cases very irregular in shape, but are generally less than three feet in width. They have various marginal characters. Some are not well marked off from the diabase, grading into it by an interlocking of crystals that leaves no definite contact, thus closely resembling the "contemporaneous veins" of Teall and Geikie. Others show decided lines of demarkation and a few have a soft green aphanitic selvage. In James Township there are numerous such aplitic veins, usually but a few inches in width and commonly gray, flesh-colored, or greenish gray. The former are chiefly composed of feldspar and quartz, while the

	1	2	3	4	5	6	7	8
SiO_2	50.69	50.80	50.48	52.25	73.07	78.28	72.33	58.84
Al_2O_3	16.11	19.42	17.03	17.97	14.88	12.00	12.99	11.24
Fe_2O_3	0.70	0.97	1.25	0.81	0.04	....	none	....
FeO	7.05	6.67	7.81	8.89	2.93	1.19	2.50	0.47
MgO	8.20	5.78	9.32	6.46	1.30	0.37	0.97	0.35
CaO	12.09	12.68	10.96	7.27	0.66	0.29	1.73	12.17
Na_2O	1.78	1.60	1.95	3.61	6.17	6.89	7.60	6.91
K_2O	0.78	0.37	0.24	1.71	0.46	none	none	none
H_2O+	1.65	0.86	0.82	1.80	0.90	0.61	1.09	0.40
H_2O-	0.16	0.25	0.22	0.04				
CO_2	....	....	....	....	....	none	1.00	9.84
TiO_2	0.53	0.43	p.n.d.	p.n.d.	0.41	0.34	0.74	0.26
CoO, NiO	0.11	0.01	0.04	....	none	....	....	....
S	0.07	....	....	....	....	....	....	..13
Sum	99.82	99.84	100.12	100.81	100.82	99.97	100.95	100.61
Rock name	Quartz-diabase	Quartz-diabase	Quartz-diabase	Quartz-diorite	Aplitic soda granite	Aplitic soda granite	Aplitic soda granite	Aplitic soda granite
Locality	Silver Bar Mine, Cobalt, Ont.	Kerr Lake Mine, Cobalt, Ont.	University Mine, Cobalt, Ont.	James Twp., Nipissing, Ont.	University Mine, Cobalt, Ont.	James Twp., Nipissing, Ont.	University Mine, Cobalt, Ont.	James Twp., Nipissing, Ont.
Analyst	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore	R. E. Hore	N. L. Bowen	N. L. Bowen	N. L. Bowen

greenish ones contain a fibrous chlorite. Frequently the aplites have a considerable percentage of finely crystalline calcite, and small crystals of titantite and grains of epidote are common. The quartz and feldspar are usually in equidimensional grains as typical in aplites, while occasionally there are micrographic intergrowths, and in some specimens rounded grains of feldspar in a matrix of later-formed quartz. Analysis by N. L. Bowen of a specimen from one of these veins is given in the table on p. 275 (anal. No. 6).[1]

On the property of the University Mine in Coleman Township is a larger fissure-filling, exposed at intervals for eight hundred feet, and in places over fifty feet wide. Analyses of specimens of this vein are given in Columns 7 and 8. The specimen No. 7 is a fine-grained gray soda granite taken from the wide part of the vein. The specimen No. 8 was taken about three hundred feet from No. 7, and is finer in grain and free from carbonates. Portions of the rock contain a high percentage of calcite, which fills interstices between the earlier-formed feldspar and quartz.

Quartz and calcite veins.—The most common type of minor fissure-fillings is composed of white quartz. Chlorite and fibrous amphibole are common constituents and pyrite, chalcopyrite, and galena are frequently present. In some of the quartz veins there is considerable calcite filling interstices between well-formed quartz crystals.

Relation of the diabase and sodic aplitic veins.—In some large sills there are portions, one to two hundred feet from the bottom, which are pink, coarse grained, and more highly sodic than the gray, medium-grained, main mass, into which they pass by insensible gradations. Similar pink-colored rocks occur as irregular-shaped masses distinctly marked off from the gray diabase. The microscopic examination shows that the pink-textured portions have a higher percentage of those minerals which were last to crystallize in the gray diabase. The aplitic veins are composed almost entirely of the chief of these last-formed minerals—sodic feldspar and quartz.

There is a lack of evidence which would indicate any extensive fusion and absorption of the intruded rocks. Xenoliths are not

[1] N. L. Bowen, *Canadian Mining Journal*, April 15, 1909; see also *Bulletin of Canadian Mining Institute*, December, 1909.

found. The pink rock has not a composition intermediate between the gray diabase and the intruded shales. It seems probable therefore that the variations in composition are the natural consequence of the cooling of a molten magma whose composition was near that of the gray diabase, except that the latter does not contain the same proportion of volatile constituents.

The aplitic veins seem to have been formed by the last secretions from the diabase magma, filling fissures which developed after most of the mass had solidified, while the pink-colored diabase and gabbro masses represent the solidification from the molten magma at an intermediate stage in a process of differentiation.

The irregular pink-colored patches and streaks were probably intruded earlier into hot but viscous portions of the cooling masses. In these cases it appears that there has been differentiation in the diabase magma but not *in situ.* Some other pink portions of the thick sills are probably the result of differentiation *in situ.*

ROCKS OF THE NIPISSING SILVER FIELDS

CENOZOIC	*Recent:*	Clay, marl, peat.
	Pleistocene	(1) Coarse unstratified material—sand, gravel, and bowlders; (2) Stratified clay with some sand.
Great unconformity		
PALEOZOIC	*Silurian:*	Grey limestone with some interbedded greenish shales, and at the base an arenaceous conglomerate. Correlated with Niagara of New York state.
Great unconformity		
ALGONKIAN	*Keweenawan:*	Igneous intrusives only. Chiefly quartz diabase and quartz gabbros with acid differentiation products. Some olivine diabase and diabase porphyrite dykes.
	Igneous contact	
	Huronian:	Sedimentary rocks only.
		(1) An upper series. Probably equivalent to Middle Huronian of Lake Superior. Chiefly feldspathic quartzite with some conglomerate.
	Slight unconformity	
		(2) A lower series. Probably equivalent to Lower Huronian of Lake Superior. Chiefly greywacke, shale, conglomerate, and feldspathic quartzite. The conglomerate pebbles are mostly of holocrystalline igneous rocks, the matrix greywacke and grey shale.

The rocks are seldom schistose except as the result of contact metamorphism.

Great unconformity

ARCHEAN *Laurentian:* Igneous intrusives only. Holocrystalline light-colored siliceous rocks. Chiefly granites, diorite, syenites, and gneisses.

Igneous contact

Keewatin: Igneous and sedimentary rocks. All are much metamorphosed, and many schistose.

The relative age of the igneous and sedimentary rocks is doubtful; but the iron formation is probably younger than much of the igneous portion. The agglomerates were probably contemporaneous with some of the non-clastic volcanic rocks, and may be contemporaneous with the other sediments. The igneous rocks are chiefly of *extrusive* types.

Extrusives:
(1) Dark-colored basic rocks—basalts—mostly with composition and texture of altered diabases.
(2) Light-colored siliceous rocks—felsites and felsite porphyries—mostly quartz porphyries which have been altered to sericite schists.

Intrusives:
(1) Basic rocks, mostly diabase and gabbro.
(2) Siliceous rocks, mostly quartz porphyries and porphyrites.

Sediments:
(1) The iron formation—chert, jasplite, carbonates, slates, and green schists.
(2) Fragmental volcanic rocks—a grey felsite agglomerate.

THE COLLECTING AREA OF THE WATERS OF THE HOT SPRINGS, HOT SPRINGS, ARKANSAS[1]

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Introduction.—The unusual interest with which the hot springs of Arkansas are regarded because of their temperature and their renown for medicinal purposes, furnishes the reason for the somewhat exhaustive consideration of the source of their waters, which follows. The conclusions herein presented were reached in the course of field work on the structure and stratigraphy of the area about Hot Springs, during the summer of 1909. The paper is written with the assumption that the waters of the hot springs are meteoric. This assumption is made partly because geologists in general have come to think of most of the ground-water as having such origin, and partly because the recent studies of Mr. Walter Harvey Weed upon the waters of these springs indicate that they are meteoric.[2]

General topographic relations of the hot springs.—In casting about for all possible sources of the waters of the hot springs, the highlands of Arkansas and Oklahoma and those of the Appalachian province command attention.

The highlands of Arkansas and the eastern part of Oklahoma are divided into a northern and a southern part, separated by the valley of the Arkansas River. The northern division consists of the Boston Mountains, which are a dissected plateau, reaching the height of somewhat more than 2,200 feet above sea-level, and a much lower area to the north of them. The southern division consists of the Ouachita Mountains, which cover an area about 50 miles wide and 200 miles long. These mountains consist of ridges, the direction of which is in the main east and west and some of which surpass 2,000 feet in height.

[1] By permission of the Chief Geologist, U.S. Geological Survey.

[2] "The Hot Springs of Arkansas," *Senate Doc. No. 282*, p. 90, Washington, D.C., 1902. Prepared under the supervision of the Secretary of the Interior.

In the Appalachian province, the Cumberland Plateau exceeds 2,000 feet and the Appalachian Mountains 6,000 feet in height.

Topography of the area about the hot springs.—The topography in the vicinity of the hot springs is shown by the accompanying relief map (Fig. 1). The springs, indicated by the cross, emerge from the western end of Hot Springs Mountain, which is known as Indian

FIG. 1.—Relief map of the Hot Springs area

Mountain east of West Branch of Gulpha Creek. Immediately north of Hot Springs Mountain is North Mountain, which continues west of Hot Springs Creek, as West Mountain. Three miles west of the springs, West Mountain swings around in a horseshoe curve and extends northeastward, and is known as Sugarloaf Mountain. Hot Springs Creek, a considerable stream, flowing southward, carries off the overflow from the hot springs and the drainage of a portion of the valley just south of Sugarloaf Mountain.

This valley is from a mile to a mile and a quarter in width. About two miles northeast of the hot springs where West Branch of Gulpha Creek cuts through North Mountain, there is a limited area with an elevation of 620 feet. The greater part of the surface, however, stands above the 700-foot contour, and the highest hills exceed 800 feet. The highest elevation at which any of the springs emerge is 640 feet.

Structure and rocks of the highland areas.—The general structure of the highland area is that of a broad syncline with its trough in the Arkansas Valley. The rocks are sandstone, limestone, and shale. Those of the Boston Mountains and the area to their north lie for the most part horizontal, but in the south half of the Boston Mountains they dip perceptibly to the south, and in the Arkansas Valley pass under several thousand feet of younger rocks.

The general structure of the Ouachita area is that of an anticlinorium dipping southward under the Mesozoic and Tertiary rocks and northward beneath those of the Arkansas Valley. The rocks are intensely folded, to which, with erosion, is due the narrow valleys and parallel ridges of the area. The folds in the main have an east-west direction, but at Hot Springs and for some distance to the west, their direction is northeast-southwest. The individual folds are not continuous for great distances, but are short and overlap each other laterally. Thrust faults, approximately parallel to the strike, and of many hundred feet displacement, occur in the Ouachita Mountains and the Arkansas Valley. The hot springs are located in the eastern part of the Ouachita area.

The stratified rocks of the Appalachian province are sandstone, limestone, and shale. Their continuity is broken by faulting, and the rocks of the Cumberland Plateau dip away from the Cincinnati arch toward the southeast. The rocks west of the Cincinnati arch are practically horizontal, and are truncated along the Embayment border. Against their truncated edges, the later rocks of the Embayment area rest unconformably.

Structure and rocks of the area about the hot springs.—Like the remainder of the Ouachita region, the area about the hot springs is intensely folded. The folds are closely compressed and all are overturned to the south. As a result, the dips are to the north. Some

of these are as low as 15 degrees and they seldom exceed 60 degrees. This means that, at the points of greatest overturning, the rock layers lie literally upside down, and, in folding, have described an arc of 165 degrees.

The surface rocks about the hot springs are shown in the following section:[1]

		Feet
Carboniferous	Stanley shale	3,500
	Hot Springs sandstone	100
Age unknown	Arkansas novaculite	380
	Missouri Mountain slate	50
Ordovician	Polk Creek shale	210
	Bigfork chert	570

The Bigfork chert is in layers from two to twelve inches thick. Throughout most of the formation, it consists almost entirely of chert, but in parts the layers are separated by thin beds of shale, and in other parts shale is the main constituent. The chert is very brittle and is intensely fractured from the folding it has suffered.

The Polk Creek shale overlies the Bigfork chert, and is a very black, somewhat siliceous shale, though soft enough from its graphitic nature to soil the fingers in handling. The upper part contains a few thin, siliceous beds, but the lower part is wholly shale.

The Missouri Mountain slate, as it occurs in the vicinity of the hot springs, is a red to brown or yellow shale, depending upon the stage of weathering. Further west in the Ouachita area, it is a true slate.

The Arkansas novaculite, as it is exposed in the vicinity of the hot springs, consists of three parts: A lower, massive one 275 feet thick, made up of heavy beds of much fractured novaculite. It is from this part of the formation that the Arkansas abrasives are secured. This is followed by fifty-five feet of very black clay shale, weathering in places to light gray; and this by fifty feet of what appears to be rotten, porous novaculite. The section of the novaculite formation over the Ouachita area varies greatly with the locality.

The Hot Springs sandstone[2] is a gray, quartzitic sandstone, in

[1] With the exception of the Stanley shale and the Hot Springs sandstone, these names were first applied to the formations as they appear in Montgomery County, Arkansas.

[2] This name has not been used before in Arkansas.

beds from three to eight feet thick. The basal ten feet is conglomeratic. It is from this formation that most of the hot springs issue, which fact, however, is not significant.

The Stanley shale is composed mainly of black to green clay shale, though a large percentage of it consists of rather soft, greenish sandstone. This shale skirts Hot Springs and West Mountains. While a large part of the city of Hot Springs stands on this formation, only the waters of those springs that issue at the lowest levels move through it.

Possibilities of ground-water flowage.—While the altitude of the Boston Mountains is sufficient to give the ground-water enough head for it to emerge at the height and distance of the hot springs, the intervening structure makes such impossible. The closely compressed folds, their lateral overlapping, and the faulting of the Ouachita area

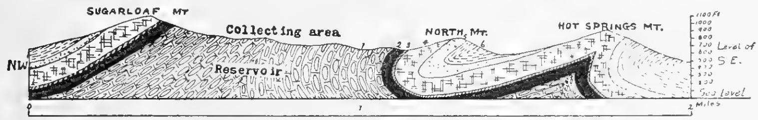

FIG. 2.—Northwest-southeast section at Hot Springs. 1. Bigfork chert. 2. Polk Creek shale. 3. Missouri Mountain slate. 4. Arkansas novaculite. 5. Hot Springs sandstone. 6. Stanley shale.

to the north and west of the hot springs are such as to prevent the uninterrupted movement of ground-water except for short distances. Likewise the stratigraphy, structure, and topography to their south eliminate that area as a possible source of the water; and the structure of the Appalachian province and the Embayment area is such as to preclude the former as a possible location of the water head.

The collecting area.—It follows from the above that the collecting area must be in the near vicinity of the springs, and a study of the topography, stratigraphy, and structure thereabout locates it with reasonable certainty. A glance at the section (Fig. 2) from Sugarloaf Mountain southeastward through Hot Springs Mountain will indicate the collecting area. The surface of the overturned, anticlinal valley between Sugarloaf and North mountains is higher than the level of emergence of the springs. The rocks outcropping over the area are the Bigfork chert and the Polk Creek shale, the former occupying most of the area.

The considerable thickness of the Bigfork chert, its much fractured nature, and the thin layers of which it is composed, all combine to make it a water-bearing formation of unusual importance. The greater number of the fine springs in the Ouachita area between Hot Springs and the western border of the state come from this horizon. In many places this formation occurs in anticlinal valleys with its highly inclined beds truncated, affording the most favorable condition for the intake of water. A glance at Fig. 2 will show that these conditions obtain in the area between North Mountain and Sugarloaf Mountain. In addition to the favorable structure for the reception of water, there is the stratigraphic condition for its retention brought about by the overlying Polk Creek shale. As a consequence of the topography, structure, and stratigraphy, the water is collected in the basin shown in the map (Fig. 1), conducted through the Bigfork chert

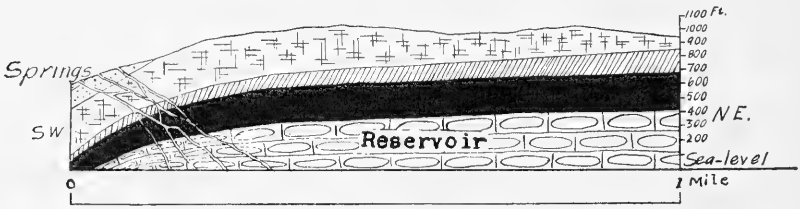

FIG. 3.—Northeast-southwest (longitudinal) section of Hot Springs Mountain, showing the hypothetical water conduits at the plunging end of the anticline. Symbols, same as in Fig. 2.

beneath the North Mountain syncline, and forced up into the Hot Springs anticline, at the western end of which it emerges in the hot springs. Including several of weak flow, there are said to be seventy-two of these springs, and they are confined to a narrow strip about a quarter of a mile long.

The exact location of the springs is attributable to the south-western plunge of the Hot Springs anticline, and as has been stated by Mr. Walter Harvey Weed[1] probably to fracturing and possibly slight faulting in the process of folding, as shown in Fig. 3.

While not relevant to the title of this paper, it might be added that the considerable number of dikes in the vicinity of the hot springs, the large number (eighty are known) only four miles to the southeast,

[1] *Loc. cit.*

on and near the Ouachita River, and the areas of igneous rock at Potash Sulphur Spring, Magnet Cove, and other near places, force the suggestion upon one that the waters of the springs owe their temperature to passing over hot rocks, or the vapor from such, in some part of their underground course. The fact that these are practically[1] the only hot springs within the Ouachita area, though there are scores of cold springs issuing from the same formations and under the same geologic relations, gives this suggestion great weight; but inasmuch as some of the hot springs are said to be unusually radioactive, there is the alternative suggestion that atomic decomposition in igneous rocks (which may have lost their magmatic heat) is the source of the high temperature of the water.

[1] Recently a spring, said to have a temperature of 98° to 100° F., has been discovered issuing from the Arkansas novaculite in the bed of the Caddo River at Caddo Gap, Montgomery County.

Reviews

Preliminary Report on a Part of the Similkameen District, British Columbia. By Charles Camsell. Geological Survey of Canada.

This report covers the region about Princeton, including the Roche River, Copper Mountain, Kennedy Mountain, and Bear Creek Mining Camps, and the Tertiary coal basin of Princeton. Copper ores occur in lodes with some gold and silver. Exploration of these deposits has been considerable, but the development is limited. Placer mining has been carried on in the district since 1860, but is of little importance now. Platinum is found in the placers with the gold. E. R. L.

Report on a Portion of Conrad and Whitehorse Mining Districts, Yukon. By D. D. Cairnes. Canada Department of Mines. Geological Survey Branch.

The district lies along the western edge or the Central Yukon Plateau region just east of the Coast Range. The ores are chiefly of gold, occurring in quartz veins, sometimes with rich values in silver. The work on these veins was begun in 1905, and has since developed rapidly. Several seams of anthracite coal outcrop in the district, and should be of considerable value in the near future. E. R. L.

Geology of the Taylorsville Region, California. By J. S. Diller. U.S. Geological Survey Bulletin 353.

The topographic elements of the northern Sierras, to which the Taylorsville region belongs, are three fault blocks with prominent escarpments to the east and long gentle slopes to valleys along the western borders. Sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age, and igneous rocks belonging to several periods are found in the region. The most important periods of igneous activity are connected with the compression and deformation of the rocks of the Sierra Nevada at the close of Jurassic, and with the great uplifting and faulting at the close of the Cretaceous. No great mines have been developed, but forty or fifty smaller ones have yielded a total value of $7,000,000, almost wholly in gold, with a little silver and copper. E. R. L.

The Lime and Cement Resources of Missouri. By H. A. Buehler. Missouri Bureau of Geology and Mines. Vol. VI, 2d series.

In this report the materials suitable for use, the properties and methods of manufacture of lime, and the various kinds of cement are described in considerable detail, the resources and development being described for each county separately. The available deposits of limestone, clay, and shale are extensive, and the industry is a very important one.

E. R. L.

Preliminary Report on a Portion of the Main Coast of British Columbia and Adjacent Islands in the New Westminster and Nanaimo Districts. By O. E. Leroy. Canada Department of Mines. Goelogical Survey Branch.

The area described embraces that portion of the coast of British Columbia between the international boundary line and the mouth of Powell River on Malaspina Strait, and lies almost wholly in the mining district of New Westminster.

The rocks in the district include sedimentary rocks of Devonian, Carboniferous, Cretaceous, and Quaternary (Glacial) age, and Paleozoic, Mesozoic, and Eocene igneous rocks. The principal ore deposits, which lie chiefly in Paleozoic rocks, are of copper and iron. The magnetite deposits are extensive, but have not been developed. A short summary of the copper deposits would add to the value of the report.

E. R. L.

The Laurentian System in Eastern Canada. By F. Dawson Adams. *Quarterly Journal of Geological Society,* Vol. LXIV, 1908, pp. 127–48, and pls. XI–XIII.

This paper is an outline of the chief results obtained from an extended study of a selected area, the object being to determine the character, structure, relations, and origin of Logan's Laurentian succession in eastern Canada.

In Logan's original classification, the Laurentian included two series, the Grenville series, and the Lower Orthoclase (Fundamental) Gneiss. The former is shown to be, in origin, a great development of Proterozoic sediments; the latter consists of great bodies of igneous rock underlying and intruded into the sediments. The term Laurentian is restricted to the underlying series. The Grenville series presents by far the greatest thickness of pre-Cambrian limestone in North America.

E. R. L.

The California Earthquake of April 18, 1906. By the State Earthquake Investigation Committee, A. C. LAWSON, Chairman. Washington: Carnegie Institution, 1909. Two vols. with Atlas. Vol. I, pp. xviii+451 (4to); pls. 146. With folio atlas of 25 maps and 15 sheets of seismograms.

The long delay in the appearance of the second volume of this report makes it advisable to call attention to the great importance of the part already published. Even without the second volume, this monograph is one of the most elaborate of any earthquake report that has yet appeared. The only reports inviting comparison upon this basis are those by the Naples Academy of Science on the great Calabrian earthquake of 1783 (xiv+351 folio pages with atlas and 69 plates); by Robert Mallet on the so-called Neapolitan earthquake of 1857 (830 pp.); by the French Academy of Science upon the Andalusian earthquake of 1884 (772 pp. and 42 pls.); and by R. D. Oldham upon the great Assam earthquake of 1897 (xviii+379 pp. with 42 pls. and 3 maps).

The already published text upon the California earthquake is in very large part an edited collection of extremely valuable data gathered by a large number of geologists, the work of correlation and presentation having been carried out by a geologist who has made important contributions to American geology. To the geologist, the seismologist, the engineer and builder, and to the general reader, the report is one of very great value, but its sphere of usefulness must be very much limited by the difficulty of procuring it (the already published portion is sold for $17.50); and to some extent also by the form of publication, since the atlas intimately illustrates the text but is so unwieldy that it cannot be kept near it in any standard library. The lack of any index whatever must also be greatly regretted, since it is only by running through the table of contents that any desired subject can be located. To illustrate, one of the most valuable sections of the work describes experiments along new lines made with a shaking machine by Mr. F. J. Rogers. It is necessary to read four pages of contents in order to find the page reference, and even then the author's name does not appear.

As regards the atlas, the folio size has apparently been fixed to allow of the introduction of fifteen 30″ quadrangles of the map of the United States, upon which by means of a single uninterrupted red line the general course of the earthquake rift is indicated. In view of the lack of all detail, it would seem that the relation of the rift to the topographic relief could be much better brought out upon a single map of correspondingly reduced scale. Throughout the report the attempt has clearly been to set down the

observations made, unmodified by special views of origin; and such a report must always remain of the greatest value, however much theories should change. A few pages only are devoted to discussion of results, and theories of cause are either briefly set forth or implied rather than explicitly stated. By many this will be regarded as unfortunate, since they will wish to know the lines of evidence by which the conclusions were reached. It appears with sufficient clearness that in the view of the chairman of the commission, the disturbance of April 18, 1906, was due entirely to a differential mass movement of the ground upon a single surface (or narrow zone) of fracture—the so-called St. Andreas Rift; and that all earlier historic earthquakes within the same province, with the exception of that of 1868, were likewise caused by movements upon this same rift. The earthquake of 1868 is ascribed to a similar adjustment upon the degraded fault along the northeast margin of the Santa Clara Valley and San Francisco Bay. Other possible displacements, within the same province at the same times, have in the report been excluded from consideration, perhaps because none were revealed through surface breaks.

It has further been assumed that the local energy of the disturbance was determined solely by distance from the rift, the apparent surface intensity, when not in harmony with this law, being accounted for solely by differences of elasticity within the sub-surface materials. This is certainly of very great interest, provided it is true; but the maps and printed observations do not make it by any means conclusive. Map No. 23 of the atlas (distribution of apparent intensity) does not make it appear even probable. Dr. G. K. Gilbert, a member of the commission, some four months after the earthquake, published a short paper in which he advanced the same theory, though he significantly added:

> But after making due allowance for differences in natural foundation and for differences in the resisting power of buildings, there remain various anomalies for which satisfactory explanation has not as yet been found. The natural foundation of Oakland is similar to that of San José, and its distance from the earthquake origin is about the same, but the injury to its buildings was decidedly less; and *Santa Rosa, standing on ground apparently firmer than that at Oakland or San José and having a somewhat greater distance from the fault, was nevertheless shaken with extreme violence.*[1]

It is too early to discuss these anomalies. With the data now in hand it seems to be true that there are outlying tracts of high intensity surrounded by areas of relatively low intensity; and these features, if they shall be fully established, will doubtless affect in some important way the general theory of the earthquake.

[1] The italics are mine.—W. H. H.

It is the discussion of such difficult but crucial points that the reader seeks in vain in the final report. Passing in review the whole history of great earthquakes, it would seem remarkable, indeed, if the cause of one were not the cause of most, if not all, such movements of the crust. A criticism of the report, which has been made by several reviewers, is that it has ignored earlier work; and, excepting only the Mallet conception of isoseismals, it seems that the report might have been written in its present form if no report upon any earthquake had ever been published.

Repetition of a recent triangulation by the U.S. Coast and Geodetic Survey was made subsequent to the earthquake and revealed important changes in the location of monuments. The report upon this resurvey by Messrs. Hayford and Baldwin is of very great interest, since a comprehensive retriangulation after a destructive earthquake has been made before in but a single instance—that of the great Assam earthquake of 1897. No attempt can be made in the compass of this review even to mention the many important subjects which are treated in the report.

W. H. H.

University Geological Survey of Kansas. Vol. IX. Oil and Gas Report, 1908 [1909]. Pp. 600; pls. and maps, 110.

The Upper Carboniferous of Kansas, because of the abundant and beautifully preserved fossils which it furnishes; because of the thickness of its exposed section and the regularly alternating structure of limestones with shaly or sandy beds, and because of the distinguished and historic names which are associated with the literature that has grown up about it, has become in some measure a standard or reference section for invertebrate paleontologists when dealing with the Upper Carboniferous of the United States. Real additions to our knowledge of this series, therefore, will be of interest to all geologists and especially to those who are engaged in stratigraphic paleontology. The latest volume of the University Geological Survey of Kansas, however, contains matter for all tastes. It is divided into eleven chapters, each of which constitutes a more or less distinct paper dealing with the wide range of subjects which the geology of Kansas naturally presents. The first chapter comprises a geological and historical account of the discovery of oil and gas (pp. 5–41). It was written by Erasmus Haworth. The second and third chapters are jointly by Erasmus Haworth and John Bennett, and give the history of field work in Kansas (pp. 42–56) and a discussion of the general stratigraphy (pp. 57–160). The three succeeding chapters are by Erasmus Haworth and are entitled, respectively, "Detailed Geology of Oil and Gas" (pp. 161–79), "Life

of Oil Wells and Gas Wells—Gas Pressure" (pp. 180–98), and "Chemical Conditions of Oil and Gas" (pp. 199–227). The second of these three chapters also includes an abstract of a paper by Dr. C. Engler on the "Origin of Petroleum" (pp. 198*a*–198*d*). Chap. vii, comprising pp. 228–302, was written by H. P. Cady and D. F. McFarland and deals with the chemical composition of gas, as the following chapter by F. W. Bushong deals with the chemical composition of petroleum (pp. 303–17). The title of the ninth chapter is "Coal-Measure Faunal Studies," by J. W. Beede and A. F. Rogers, and it comprises pp. 318–85. The last two articles were written by E. H. Sellards, who deals with "Fossil Plants of the Kansas Upper Paleozoic" (pp. 386–500), and "Fossil Cockroaches in the Kansas Coal Measures and Kansas Permian" (pp. 501–41).

The one of these papers which the writer's studies permit him to discuss most intelligently is that by Beede and Rogers on the Faunal divisions of the Kansas Coal Measures. This is a subject well worthy of investigation for if correlations are to be made with the Kansas section, it will probably be more with groups than with individual formations, some of which are only a few feet in thickness. Previous groupings of the formations had been suggested by authors, partly on considerations of stratigraphy, partly, as in Prosser's stages proposed for divisions in the upper portion of the section, on paleontologic evidence, but nothing which was as comprehensive and consistent involving the formations of the entire series and based on such an accumulation of data. In this connection it seems unfortunate that the classification and nomenclature of Beede and Rogers, resting it would appear especially on paleontological evidence, does not agree with that of Haworth and Bennett in the same volume, which appears to have sprung from considerations of lithology, topography, etc. Although I have myself studied the Kansas faunal sequence in a somewhat incidental and dilettante manner, I am not prepared with any criticism of the validity of the groups proposed. These will stand or fall as they meet the test of experience, but the authors certainly know the Kansas section better than any other paleontologists and there is no reason to doubt that their classification is, taken all in all, the best that has been proposed.

It seems rather doubtful, however, after reading their paper, whether the Kansas section can be used as a reference section with any degree of advantage. The authors find such variations in the faunas collected at different points in certain of the formations that were it not for their stratigraphic connection they would hardly be believed to be the same horizon. In my own work on the Kansas faunas similar anomalies were observed which led me to suspect the correctness with which the beds had been traced.

The generalization of the formational fauna by means of collections taken at numerous and widely separated stations does much to eliminate the false premise otherwise involved and doubtless the limit of error is still farther reduced by considering not the faunas of individual formations but of groups of formations. For this reason a grouping of the Kansas beds was especially desirable.

Some of the faunal modifications are regarded by the authors as the result of conditions of sedimentation, while others are ascribed to barriers, location and character not specified. Diversity of fauna at different points in the same bed of limestone can clearly not be ascribed to the interference of barriers nor probably can the fact that the shales with which the limestones alternate are usually almost barren of fossil shells, or at times contain invertebrate faunas of appreciably different facies from the adjacent beds of calcareous nature. Since now we have faunal variations, some of which can clearly be assigned to environmental causes, the propriety seems doubtful of explaining others by hypothetizing a different cause.

The classification proposed by Messrs. Beede and Rogers may be summarized as follows: The forty-six formations from the Cherokee shales below, to, and including the Neosho formation, to which limits the authors confine the Pennsylvanian, are divided into ten stages containing from one to nine formations each, and the stages are again grouped into four series, each of which contains two or three stages. The basis for this classification is presented in the form of two charts, one of which is of such novel construction that it requires the second as a key to it.

This table seems especially designed to show the abundance of species in the different formations, a fact to which the authors attach much importance, because they connect it with the ability to migrate. They say, "Another point of some significance which may be determined by the chart is the time at which migration of individual species is most apt to occur. It is well understood that the most vigorous species, represented by large numbers of individuals, are the ones that migrate most readily, other things being equal, and form the cosmopolitan elements of the various periods" (p. 327). And also below on the same page: "Other things being equal, it is believed that a species is more apt to withstand the vicissitudes of migration at this time [its culmination] than at any other on account of its greater numbers and reproductive ability and greater vitality." Now some of the fundamental facts in these statements seem doubtful to me. Are the species represented by large numbers necessarily the most vigorous? Are the most vigorous species the ones that migrate most readily, other things being equal? And are other things ever equal? As to the time of migra-

tion of any one species the case stands perhaps a little better. But even so, the migration of species is governed by so many factors extrinsic as well as intrinsic that inferences drawn from the fact of abundance can hardly lead to any trustworthy conclusions.

In short, it seems to me that the authors attach too much and possibly not altogether the correct significance to the fact of abundance. At all events, the matter is not so lightly to be disposed of.

Regarding their identification, the authors say that they have used conservatism: "Usually, where there is a question concerning the advisability of splitting up an older idea of a species, the old idea is followed here." As the paper is not accompanied by descriptions or figures, it is impossible for the reader to ascertain what breadth of specific limitation is assumed in any case. For my own part, it has always seemed to me that the relations between faunas are best shown when the discrimination of species is made with the keenest criticism, tempered with good judgment. It is to be hoped that in their final account of the fauna which the authors lead us to expect a refined discrimination of species will be employed.

The authors note some departures from the taxonomic nomenclature employed in previous papers which the present one in a way seems to summarize and be the fruit of, but the changes are hardly enough to bring the paper abreast of the time in this particular. These changes are, however, purely nomenclatural and do not necessarily affect the accuracy of the conclusions arrived at. They can the more be pardoned because the volume has been a long time in press and doubtless some of them came to the authors' attention after the report had left their hands.

The paper abounds in typographical errors, chiefly in connection with scientific names, and in other errors for which the printer cannot be blamed. One of the most serious, at least in the estimation of a paleontologist, is that the imprint is for the year 1908, while, as is apparent, the work really did not appear until late in 1909.[1] This, of course, cannot be laid at the door of Messrs. Beede and Rogers, nor perhaps the fact that the description of the chart begins on p. 359, while the chart is inserted thirty pages earlier, although in the description it is said to follow, thus really confusing

[1] In his review of my report on the Guadalupian fauna (*Jour. Geol.*, XVII [1909], 672), Dr. Beede justly criticizes that book for the same fault. I take this occasion to put the facts on record. The pages were approved with the imprint 1908 on November 14 of that year. Under ordinary conditions this would have given ample time for publication before the end of the year, but owing to occurrences which could not be foreseen publication was delayed. The copies were received on January 29, 1909, and were immediately distributed so that the actual date of publication should probably be regarded as early in February.

the reader. Such errors, however, as ascribing *Seminula argentea* to Morton instead of Shepard, as citing a species of Leda under Nuculana and Leda, two genera which are recognized as being synonymous, and other similar instances, must be credited to the authors alone.

It is doubtless illogical, but it is certainly true, that carelessness in such matters as these, in style and editorship—in brief, carelessness in form in which the work is presented—somehow leads the reader to infer carelessness in the work itself, an imputation which in the present case I do not believe to be deserved but which the authors might do well to guard against in the case of a less friendly critic.

G. H. G.

The Genesis of Loess a Problem in Plant Ecology. By B. SHIMEK. Iowa Academy of Science, pp. 57–64; date not given on separate, probably 1909. Pls. III–VII.

The Loess of the Paha and River-Ridge. By B. SHIMEK. Iowa Academy of Science, pp. 117–24, pls. VIII–XII.

These are critical papers full of important data assembled by a careful observer. They bring strong support to bear in favor of the eolian hypothesis of the loess. The first paper is also notable as an added recognition of the value of uniting the methods of two sciences in the study of composite problems.

T. C. C.

Aftonian Sands and Gravels in Western Iowa. By B. SHIMEK. Bulletin Geological Society of America, Vol. XX, 1909, pp. 399–408, pls. 33–37.

This important paper adds much new data to the distribution and constitution of the Aftonian formation and announces molluscan remains in addition to the mammalian fossils found recently by Calvin and the vegetal remains found earlier. These remains, taken with unconformities also described in this paper, made it clear that the Aftonian is a true interglacial deposit formed under mild climatic conditions and not simply a fluvial phase of the preceding or following ice-deposits.

In a supplementary note Shimek proposes the name Nebraskan for the Sub-Aftonian glacial formation because of what he deems objections to the previous terms Albertan and Jerseyan and an implied objection to the descriptive term Sub-Aftonian. But the facts (1) that the locality at which the formation was first found and its relations first pointed out is in Iowa, (2) that most of the localities now known are in Iowa, (3) that it has

merely been traced into Nebraska recently and incidentally rather than as a part of a critical revisionary study, and (4) that the original locality remains quite as accessible and more typical than the localities in Nebraska, unite to make this proposal of a fourth title a proceeding of doubtful wisdom.

T. C. C.

Die Diamantführenden Gesteine Südafrikas. Ihr Abbau und ihre Aufbereitung. By DR. PERCY A. WAGNER. Pp. 207, 29 text figures, and 2 plates. Berlin: Gebrüder Borntraeger, 1909.

One of the fascinating problems of South African geology is the formation of the peculiar kimberlite pipes and the origin of the diamonds which have made them so famous. This new work will be welcomed as a contribution to that interesting subject. It describes carefully the different phases of the kimberlite which fills the pipes, from the but scarcely altered hardibank through the hard blue ground, soft blue ground, to the completely altered, hydrated, and well-oxidized yellow ground near the surface. The point is made that within the pipes distinct zones can be traced from top to bottom. Because certain individual characteristics, both of the general material and of the diamonds as well, can be traced throughout each zone, several observers have concluded that the pipes were formed and filled by several distinct volcanic eruptions. But the nature of the eruptions which produced these great pipes, and at the same time filled them with breccia, volcanic tuff, and a rather heterogeneous mass of material derived in part from the deep-seated rocks, but containing also fragments of sedimentary formations occurring at higher horizons, has not been brought out very clearly and is perhaps not yet well understood. Contact metamorphic phenomena appear to be of rather limited extent.

An interesting feature described by the author is that, on account of the serpentinization of the olivine in the filling of the pipes, the material has, in some cases, undergone a marked increase in volume. This increase in volume has caused the filling to swell upward and this process has resulted in the striation of the walls of the pipe.

The three principal hypotheses of the origin of the diamonds are discussed. The author argues against the view held by some South African geologists that the diamonds have been derived from disrupted deep-seated eclogites, and favors the theory that the diamonds were developed in the midst of the magma from its own inherent constituents.

Chapters describing in detail the minerals of the pipes and dikes and dealing with the petrography make up about half of the book. The work

ends with chapters on the methods of mining and the statistics of the diamond-mining industry.

R. T. C.

Geographical Essays. By WILLIAM MORRIS DAVIS. Edited by DOUGLAS WILSON JOHNSON. Pp. 777, 130 text figures. Boston: Ginn & Co., 1909.

An endeavor has been made in this volume to meet the growing demand for an edition of Professor Davis' most important geographical essayss Twenty-six of these essays have been reprinted from the pages of the variou. publications in which they originally appeared and grouped under two heads: Part I, embracing twelve educational essays, and Part II, fourteen physiographic essays. The high character of these essays is so familiar to all geologists and geographers that special comment seems superfluous.

R. T. C.

The Cement Resources of Virginia, West of the Blue Ridge. By RAY S. BASSLER, PH.D. Bulletin No. 11 A, Virginia Geological Survey. Pp. 309, 30 plates, and 30 text figures. Charlottesville, 1909.

This report deals essentially with the limestones and shales of Appalachian Virginia—in other words, with the materials there present which may be used in the manufacture of cement. The Cambro-Ordovician limestones have received the greatest attention, though the post-Ordovician cement materials are also discussed toward the close of the book. A large number of chemical analyses of the limestones from the various localities are given. Since practically nothing concerning the Paleozoic fossils of Virginia has appeared in the literature, the author has included plates portraying some of the characteristic species employed in the discrimination of the different formations. The report is well illustrated.

R. T. C.

Hygienic Importance of Dustless Conditions in School Buildings

The problem of preserving hygienic conditions in school buildings is one that deserves the serious attention of those responsible for the health of pupils under their care.

Ample ventilation and scrupulous cleanliness are vital, but unless the floors receive proper attention and treatment the dust that accumulates will be a constant menace, for dust is recognized as the greatest carrier and distributer of disease-germs known.

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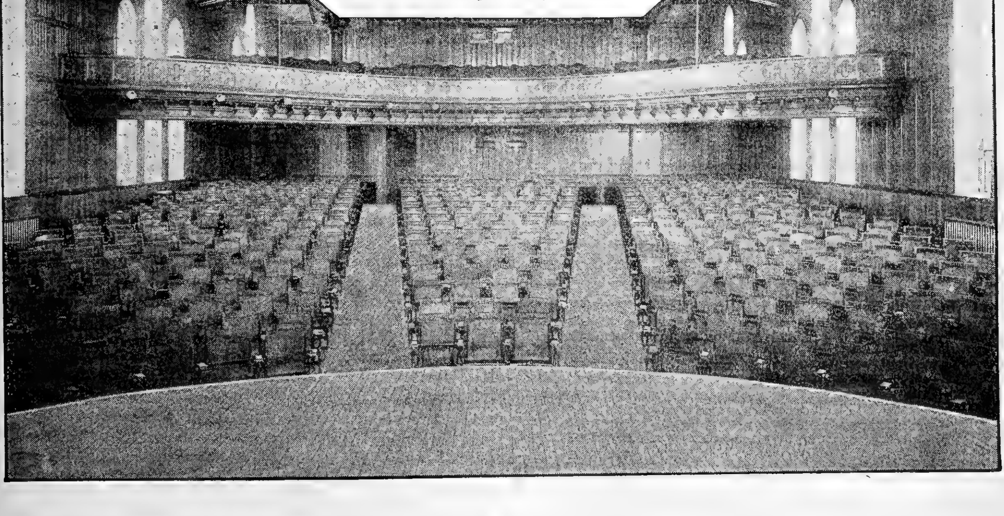

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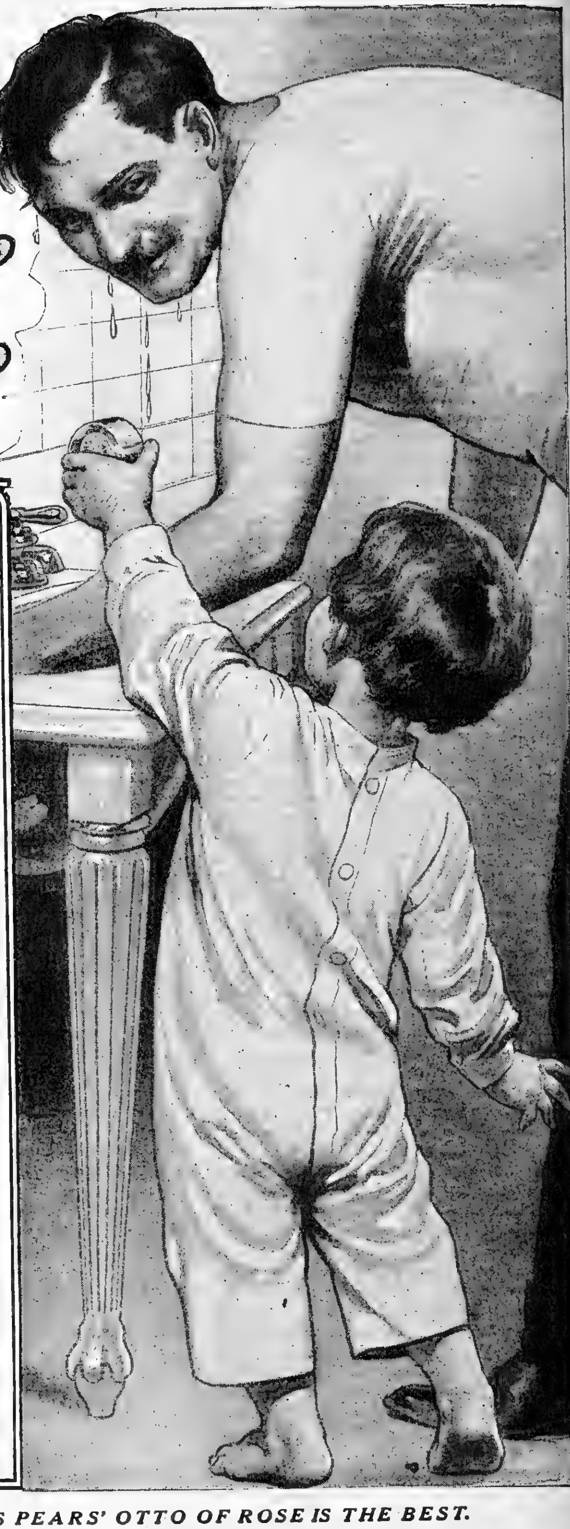

THE

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ORIGIN OF THE PEGMATITES OF MAINE[1]

EDSON S. BASTIN
U.S. Geological Survey

During a portion of the summers of 1906 and 1907 I had the opportunity to study in some detail the pegmatite deposits of Maine, and at intervals during succeeding years have been able to pay brief visits to commercially important pegmatite deposits in Connecticut, New York, Pennsylvania, and Maryland. Without entering into the details of the field occurrences, which will be described in a forthcoming bulletin of the U.S. Geological Survey, I wish to summarize here the more important scientific results of these studies. Particular acknowledgment is due to Dr. Whitman Cross of the U.S. Geological Survey, for valuable criticism and advice in this work.

The pegmatite deposits in the state of Maine all belong to the type commonly known as granite pegmatite, its dominant minerals being the same as those which are most abundant in ordinary granites. Pegmatites are most abundantly developed in the western and southwestern part of the state, and are invariably associated with granites. Excellent exposures in the feldspar and gem quarries, on glaciated ledges, and especially along the seashore in the Boothbay Harbor region, afford unusual opportunities for detailed field studies.

General geologic relations.—The pegmatite masses vary in size from extremely small stringers intimately injected between the foliae of schists and thus forming injection gneisses, to batholitic masses

[1] Published with the permission of the Director of the U.S. Geological Survey.

a mile long and one-half mile wide, showing coarse pegmatitic textures throughout. Most commonly the pegmatite masses are roughly lens-shaped and lie parallel to the foliation of the inclosing schistose rocks, their attitude being dikelike or sill-like, according as the schists lie at steep or gentle inclinations.

The rocks associated with the pegmatites are granite gneiss, granites of various textures, and schists of sedimentary origin. The field relations show that the pegmatites are invariably intrusive into the sedimentary schists, frequently cutting sharply across the schist foliae though usually intruded parallel to them. Characteristic contact metamorphic minerals are sometimes developed. Into the granite gneisses the pegmatites are also in some instances distinctly intrusive, but in other cases their relations indicate that the two rocks are nearly contemporaneous and probably related in origin.

The relations between the pegmatites and the granites indicate beyond reasonable question that the two rock types are genetically related. Evidence of this is found (1) in the fact that the predominant minerals in both rocks are the same; (2) in the occurrence of granite in all districts where pegmatites are found, and (3) in numerous observed instances of transition from granite to pegmatite. One of the most instructive instances illustrating such transition is exposed on the shore of Boothbay Harbor, and is illustrated in Fig. 1. Microscopic examination of the fine-grained granite and the pegmatite in this occurrence shows that the mineral species in the two rocks are identical, the sole differences being in the texture and the proportions of the constituents. In other instances small irregular segregation-like masses with pegmatitic texture are wholly inclosed by normal granite. Although in certain instances distinct dikes of pegmatite cut the granites and in other instances dikes of granite cut the pegmatites, there is no evidence that the two rocks are of widely different ages or that there was more than one general period of granite and pegmatite intrusion. The granites are known to be of late Silurian or early Devonian age, and it is probable that the pegmatites are to be similarly correlated. With the exception of certain diabases, the granites and pegmatites are the youngest known igneous rocks of the state.

Mineral composition and texture.—As already stated, the dominant

pegmatite minerals are those characteristic also of the normal granites; namely, quartz, orthoclase and microcline, albite or oligoclase, muscovite, biotite, and black tourmaline. Accessory constituents nearly always present are garnet, magnetite, and green opaque beryl. Accessory minerals which are present only in certain pegmatites number

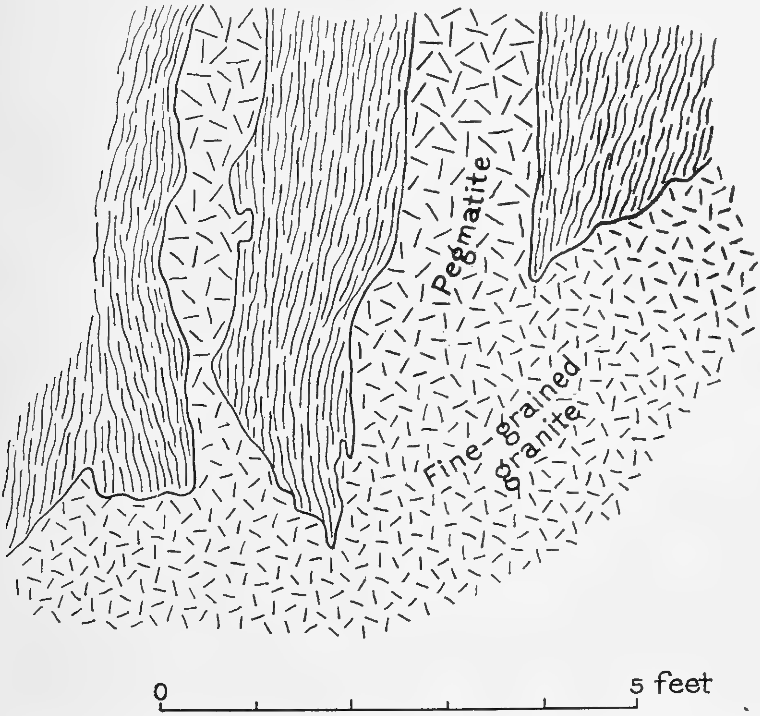


FIG. 1.—Granite grading into pegmatite and both intrusive in schists. Shore of Southport Island near south entrance of Townsend Gut.

over fifty species; the most important are lepidolite, amblygonite, spodumene, blue, green, and pink tourmaline, transparent blue, green, or golden beryl, colorless to amber-colored topaz, and rose and amethystine quartz. A number of pegmatites have been successfully worked for certain of these gem minerals.

In possibly ninety-nine one-hundredths of the pegmatite masses in the state no unusual minerals are present, the constituents being the same as in the normal granites and the proportions also somewhat

similar. The principal variations in composition involve (1) an increase in silica, (2) an increase in sodium and lithium, and (3) an increase in fluorine. The increase in silica content manifests itself in a greater abundance of quartz. Pegmatites unusually rich in quartz are less common in Maine than in certain other pegmatite districts of the eastern United States, but it is quite possible that many of the quartz dikes occurring in southern Maine were derived from pegmatite

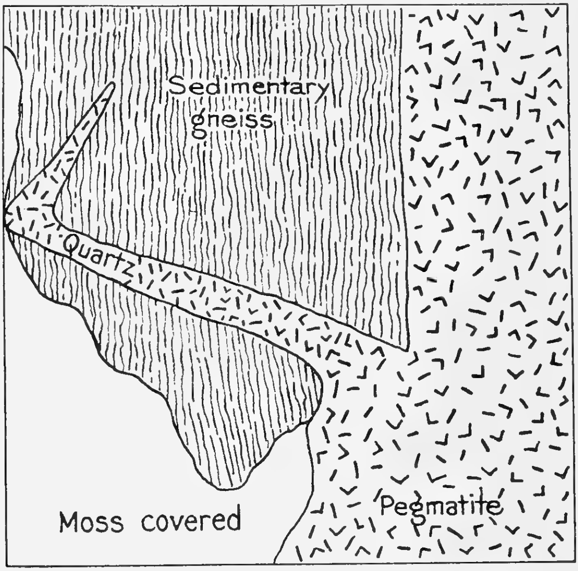


FIG. 2.—A quartz offshoot from pegmatite, $2\frac{1}{2}$ miles northeast of Paris. The branch vein is pegmatite for a short distance beyond the main pegmatite mass, but beyond this grades into pure quartz. The area illustrated is about 4 feet square.

magmas. This is suggested by the fact that certain of these masses contain occasional crystals of feldspar, black tourmaline, or beryl. In one instance, the transition from pegmatite to quartz vein, illustrated in Fig. 2, was observed. The second variation, involving an increase of sodium and lithium, shows itself in the development of occasional pegmatite masses which are rich in albite, lepidolite, spodumene, colored tourmaline, and amblygonite. The tourmaline mines of the state are in deposits of this type. The third variation, involving an increase in the fluorine content, is exemplified by occasional pegmatite masses which contain topaz, fluorite, herderite, hamlinite,

certain types of apatite, etc. Increase either in sodium and lithium or in fluorine is usually accompanied by an increase in phosphorus content. The pegmatite characterized by these rarer minerals constitutes only an exceedingly small part of the total volume of pegmatite in any district.

In coarseness, the pegmatites vary from little coarser than normal granites to masses showing single crystals of feldspar 20 feet across. Their distinguishing feature is therefore not coarseness but extreme irregularity of grain. Distribution of the constituent minerals in bands, such as is observed in pegmatites in some other regions, is entirely absent in Maine, the minerals usually (except for the graphic intergrowths) being distributed with complete irregularity. Graphic intergrowths are very abundant and include those of quartz with feldspar and less frequently of quartz with muscovite, feldspar with muscovite, garnet with quartz, black tourmaline with quartz, and spodumene with quartz. All of these intergrowths may occur in the same pegmatite mass.

Cavities are practically absent from the finer-grained pegmatites, and in most of the coarse-grained pegmatites constitute less than 1 per cent of the total volume. The gem-bearing pegmatites, however, are usually characterized by a central zone in which albite, lepidolite, tourmaline, amblygonite, etc., are particularly abundant and in which miarolitic cavities are also quite abundant. It is on the walls of such cavities that the gem tourmalines were developed. At Mt. Mica, which is the largest and most famous tourmaline locality in Maine, the largest pocket found was $20 \times 12 \times 7$ feet, but the majority do not average more than a foot or two in diameter. Only a few of these pockets contain gem minerals in any considerable amounts, but groups of quartz crystals are developed on the walls of many others.

Origin.—The writer does not purpose in this article to attempt a discussion of the voluminous literature on pegmatites except in so far as it bears closely upon those of the region under discussion. Previous writings and theories have been well summarized by George H. Williams[1] and especialy by Brögger.[2]

[1] George H. Williams, *Fifteenth Ann. Rept. U.S. Geol. Survey*, 675–84.

[2] Brögger, "Der Syenitpegmatitgange der südnorwegischen Augit und Nephelinsyenite," *Zeitschr. f. Kryst.*, XVI (1890). Sections on genesis translated in *Canadian Records of Science*, VI (1894), 33–46, 61–71.

If, as seems necessary from the field evidence, we admit a genetic connection between the pegmatites and granites, it is next of importance to inquire what evidence is afforded by the Maine pegmatites as to the physical and chemical conditions which resulted in the crystallization, from related magmas, of rocks of such widely varying character.

Influence of external conditions.—Differences in external conditions at the time of crystallization appear inadequate to explain the observed textural differences. This is shown by the close associations of the two types of rocks, already cited as evidence of their genetic relationships. The field relations show that in many instances the external conditions, such as the nature and temperature of the wall-rock, depth at which solidification took place, etc., were similar for both types of rocks. In cases, such as shown for example in Fig. 1, the general external conditions must have been practically the same for both rocks. A similar conclusion is justified in numerous other instances where granite and pegmatite grade into each other and especially in cases where pegmatite forms segregation-like masses wholly inclosed in granite. Conversely, the broad general similarity of the pegmatites over very large areas where the external conditions were certainly *not* constant also indicates that the causes of their peculiar textures were in the main internal rather than external. It seems necessary to look therefore to differences inherent in the magmas themselves for an explanation of the textural variations.

Influence of dominant constituents.—The characters shown by the Maine pegmatites accord with the evidence obtained from many other districts in indicating that the pegmatite magma were characterized as a general rule by the presence of certain components in larger amounts than in normal granite magmas and that these differences in composition were in large measure responsible for the differences in texture. The exact nature of such differences is, however, more largely a matter of inference than of direct field observation.

In the great mass of the pegmatite, what may be termed the *normal* pegmatite, it is exceedingly difficult, if not impracticable, to make a satisfactory estimate of the relative proportions of the different mineral constituents, but as far as can be judged without measurements the proportions are of the same general order as in the normal granites,

except that the pegmatites are probably on the average slightly more quartzose, a conclusion which seems warranted by the frequent transitions from pegmatite masses into veins composed largely or wholly of quartz. As is well known, the highly quartzose types show as typical pegmatitic textures as the less quartzose. The difference in the proportions of the *principal* mineral constituents in the normal granites and the normal pegmatites seems, therefore, insufficient to account for the great difference in their textures. It appears necessary to seek the cause of these contrasts in differences in the proportions of minor constituents or in the presence in the granite or pegmatite magmas of constituents which have since escaped, or which through occlusion are not now visible to the unaided eye, in the derived rocks.

Influence of minor constituents.—The presence in many pegmatites of unusual minerals, such as fluorite and other fluorine-bearing minerals, lithium minerals, boron and phosphorus minerals, and occasionally the rare earth minerals, has led certain geologists[1] to attribute to some of these substances an important rôle in the production of pegmatite textures. It cannot be doubted that when present in magmas such substances have some influence upon the texture of the resulting rock. It has not been demonstrated however that the presence of these unusual constituents is essential to the development of typical pegmatitic textures. In the opinion of the writer their presence is probably *not* essential. The pegmatites which earliest attracted the attention of American mineralogists and geologists and which have been most often described in the literature were naturally those in which unusual minerals were present in especial abundance or in perfection of crystal form. Such pegmatites constitute, however, only an exceedingly small proportion of the pegmatite in any district and must be regarded as unusual rather than normal types. The writer is familiar with certain deposits showing typical pegmatitic textures, which have been worked for their feldspar for years with the discovery of few if any of the rarer minerals.[2] In the great majority of the pegmatites of Maine unusual minerals are of

[1] Certain French geologists in particular have been advocates of this view. See De Lapparent, *Traité de géologie*, 4th ed., 639 (1900); and De Launay, *La science géologique*, 557–58, 582–83 (1905).

[2] The Andrews feldspar quarry in Portland, Conn., the Frost feldspar quarry in Maryland, and the Goldings feldspar quarry in Georgetown, Maine, are examples. See *Bull. U.S. Geol. Survey No. 420*, 31, 50, and 75.

such infrequent occurrence as ordinarily to escape detection entirely. In pegmatities where they are present their paucity or abundance seem to have small influence on the textures developed. Those inclined to attribute large influence in the development of pegmatitic textures to the presence of rare constituents usually contend that a more careful study will show that their scarcity is apparent rather than real. Such an assumption is not in accord with the field observations of the writer in Maine and other parts of New England, and appears unwarranted.

Influence of gaseous constituents.—If neither the dominant nor the rare minerals of the pegmatites have been controlling factors in the development of typical pegmatitic textures, it appears necessary to seek an explanation in the presence in the magmas of certain constituents which have subsequently escaped or at least are not readily recognized in the resultant rock. The fact that large crystals cannot be obtained at atmospheric pressures from simple dry melts of the commoner rock-forming minerals suggests at once that the crystallization of these minerals in nature took place either under widely different physical conditions (such as high pressure) or in the presence of certain substances which are scarce or absent in the rocks as now exposed. It has already been shown from field evidence (p. 302) that in many instances differences in pressure or other external conditions at the time of crystallization cannot reasonably be appealed to, to explain the textural variations observed. In such cases an appeal to the escaped constituents of the magma appears unavoidable. The same conclusion appears necessary when we consider the extreme viscosity exhibited (under atmospheric pressures) by silica, orthoclase, and albite near their melting temperatures. The various forms of silica which have been artificially produced have all crystallized from a melt so viscous as to be virtually a glass.[1] In the case of orthoclase the viscosity of its melt is so great that all attempts to crystallize the mineral from it have been unsuccessful. Since increase in pressure *per se* can hardly be appealed to as increasing molecular mobility[2]

[1] See Day and Shepherd, "The Lime-Silica Series of Minerals," *Amer. Jour. Sci.*, XXII, 271–73 (1906). Also Day and Allen, "The Isomorphism and Thermal Properties of the Feldspars," *Publications of the Carnegie Institution of Washington No. 31*, 28–29, 45–55 (1905).

[2] See Harker, *The Natural History of Igneous Rocks*, 163–64 (1909).

in magmas, it seems necessary again in accounting for the large crystals developed in the pegmatites to postulate the presence in the magma of some substance or substances not now recognizable in the derived rock. That the presence of volatile constituents in a magma does influence the viscosity is shown by the fact that certain obsidians may be readily melted with evident fluidity and the escape of gases, but that their refusion after such gases have escaped is much more difficult. Prof. Iddings[1] has also shown from a microscopic study of the obsidian of Obsidian Cliff, Yellowstone National Park, that where there was more dissolved gas the conditions were more favorable for crystallization than in other parts of the magma.

Among those constituents of magmas which might escape, leaving little record of their former presence, water gas and hydrogen are probably the most abundant, as is plainly indicated by analyses of the gases still remaining in igneous rocks[2] and by studies of the gases emitted from volcanic vents.[3]

The presence of water gas in association with subordinate amounts of other gases and of certain unusual substances (mineralizers) has been considered by many observers to be the competent and effective cause in the development of pegmatitic textures. With this opinion the present writer is in general accord, though the persuasion is based more largely upon the process of reasoning already outlined than upon field evidence of high water content or relatively low viscosity in pegmatite magmas. The field evidence gathered in the study of the Maine pegmatites must be looked upon as merely suggestive; anything like a complete solution of the problem will in all probability wait upon synthetic laboratory experiments upon the interaction between gases and rock-forming silicates.

The small weight of the gaseous and liquid constituents of most igneous rocks as compared with the total weight of the rock might lead one to question their competence to affect notably the viscosity

[1] J. P. Iddings, *Seventh Ann. Rept. U.S. Geol. Survey*, 283–87 (1888); *idem, Igneous Rocks*, 185 (1909).

[2] See R. T. Chamberlin, "The Gases in Rocks," *Publications of the Carnegie Institution of Washington No. 106* (1908). This includes a summary of earlier investigations.

[3] For a review of the literature on volcanic gases, see Clarke, "The Data of Geochemistry," *Bull. U.S. Geol. Survey No. 330*, chap. viii (1908).

of magmas and to produce large textural variations. In this connection it may not be out of place to call attention to a possible application of Raoult's Law.[1] This law states that if various substances are dissolved in equal amounts of the same solvent in the proportions of their molecular weights the resulting lowering of the freezing-point of the solution will be the same in each case.[2] In other words the effect produced is a function of the number of molecules concerned and is not primarily dependent on the nature of the substances introduced. It follows that a small amount by weight of a substance of low molecular weight (such as H_2O, mol. wt. 18) will exert the same depressing influence on the freezing-point of the solution as a much greater weight of a substance of high molecular weight (such as Fe_2O_3, mol. wt. 160), and that given equal weights of the two, the substance of low molecular weight will exercise much the greater influence. This law has been found to apply strictly only to very dilute solutions where there is no chemical action between solvent and dissolved substance. It has been applied bodily by Vogt[3] to rock magmas, but the wisdom of such extension to cover widely different and much more complex physical conditions may well be questioned. It seems not unreasonable, however, to attribute some general importance to this principle in rock magmas, to the extent that magmatic constituents of low molecular weight may exert greater influence in lowering the freezing-point, decreasing viscosity, and affecting textures than constituents of high molecular weight. They may thus attain an importance which appears disproportionate to the small part by weight which they form of the whole magma. The substances (hydrogen, water, fluorine, chlorine, and boron) commonly believed to exert the greatest influence upon the viscosity of magmas and the textures of the resulting rocks are all substances of much lower molecular weights than silica and the rock-making silicates and oxides, even when the minimum values for the latter are assumed. The hiatus between the molecular weights of these two groups of substances is so marked as to justify the retention of the term "mineralizers" for the lighter group, in case the

[1] See Ostwald, *Outlines of General Chemistry*, 136–37 (1895).

[2] Neglecting electrolytic dissociation, which is probably of small importance in rock magmas.

[3] See Vogt, *Die Silikatschmelzlosungen*, II, 128–35 (1904).

principle outlined above is eventually shown to be operative to an important degree in magmas. It is perhaps unnecessary to add that other causes besides low molecular weight may be effective in reducing viscosity in magmas.

Field and laboratory evidence bearing upon viscosity and gas content.—The field and laboratory data on the pegmatites of Maine which bear upon the viscosity or gaseous content of the pegmatite magmas may be set forth as follows. Since the pegmatite magmas crystallized at some distance below the surface, the gases which they contained must either have made their escape through the wall-rocks or else have remained in cavities or occluded within the solid pegmatite mass. The escape of such materials through the wall-rocks should presumably leave some record in contact metamorphic effects. Their retention within the rock should presumably be recorded in an especial abundance of miarolitic cavities and fluid or gaseous inclusions. The field studies of the writer in Maine and other parts of New England show that the granites are almost wholly devoid of miarolitic cavities of any kind. An isolated cavity of small size is occasionally met with but its walls are usually more or less pegmatitic in texture. In the great bulk of the pegmatites of Maine, particularly the finer-grained ones, such cavities are also exceedingly rare. In the coarser pegmatites, however, they are a characteristic feature, though usually, as far as can be judged, constituting considerably less than 1 per cent of the total volume of the pegmatite. Within the very limited gem-bearing zones of certain pegmatites miarolitic cavities may form a considerably larger percentage of the total volume. Such cavities have been attributed by various writers to shrinkage of the pegmatite mass in crystallization. This may in fact play some part in their formation but that they are not entirely the result of shrinkage but on the contrary were filled or partly filled with some material which has since disappeared, is shown by the presence of perfectly developed crystals of quartz, tourmaline, and other minerals projecting inward from the walls of the cavities. Some filling must have been present from which such crystals derived the materials for their growth. It is probable therefore that immediately after the crystallization of the main body of pegmatite the miarolitic cavities were completely filled with a gaseous solution which may later have liquefied and has since

disappeared. Water gas probably formed the bulk of this cavity filling, though carrying numerous other substances in solution. The abundance of quartz crystals on the walls of these cavities indicates that silica was one of the most abundant of these dissolved substances.

If the presence of larger amounts of gaseous constituents is responsible for the crystallization of the rock with pegmatitic rather than granitic texture, we might reasonably expect greater size or abundance of microscopic fluidal or gaseous cavities in the pegmatite minerals than in those of the normal granites. With this idea in mind the writer attempted a microscopic measurement of these inclusions in pegmatites and associated granites from Maine. On account of the uneven distribution of the inclusions in bands traversing the minerals accurate estimates were found to be impracticable and the results were negative or inconclusive. It was found moreover that some of the bands of fluidal cavities in the quartz of pegmatite were formed later than shearing movements which had affected the quartz. The inclusions in the pegmatite were similar in character to those in the normal granites of Maine, and any differences in their size and abundance in the two types of rocks were not sufficient to be noted on casual inspection.

If the pegmatite magmas are characterized by considerably larger proportions of gaseous constituents than are present in the granite magmas, we might expect notable differences in the contact metamorphic effects produced by the two types of rocks, since such effects are believed to be produced largely by gaseous and fluid emanations from the cooling igneous masses. Field observations in Maine fail to show that contact metamorphic effects, due to the intrusions of pegmatite, are notably greater than those produced by the granites. The effects produced by both are usually slight and in many instances almost nil. Masses both of pegmatite and granite frequently cut across the foliation of schists without any distortion of the latter, the contacts being of knife-edge sharpness. In other instances pegmatite has produced some softening of the bordering rock. Such effects are confined however to the immediate vicinity of the pegmatite, usually to a zone a few inches in width, and are the exception rather than the rule, most pegmatite contacts being exceedingly sharp and free from all evidence of softening. Absorption (except in a few doubtful instances) appears to be wholly absent, the contacts, even in the cases

where softening is shown, being sharp, and the pegmatite next the contact showing no difference in composition from that at some distance away. Where schist fragments are inclosed in the pegmatite their sharp outlines are preserved.

If the physical conditions of the pegmatite and granite magmas were notably different at the time of their intrusion, it would be natural to expect some differences in the forms assumed by the granite and pegmatite masses. While in many cases the forms assumed by the two types of rocks are similar there is in general a tendency for the smaller pegmatite intrusions in the foliated rocks to assume the form of a succession of lenses while granite intrusions of similar size tend to be more nearly parallel-walled. This contrast is particularly noticeable in the Boothbay Harbor region and near Rumford Falls and is probably expressive of slightly greater rigidity in the granite than in the pegmatite magma and also of greater softening of the inclosing schist by the pegmatite than by the granite magmas. The great size of certain pegmatite masses, such as Streaked Mountain in Hebron, is on the other hand suggestive of physical conditions in some pegmatite magmas not widely different from those obtaining in normal granite magmas. The crest of Streaked Mountain was examined for over half a mile of its length, and the width of outcrop examined across the trend of the ridge was also about half a mile. The whole area traversed and the remainder of the mountain as far as it could be seen was underlain almost exclusively by coarse pegmatite, the mountain being a "boss" of this material. The pegmatite is of the usual granitic type and exhibits no more than the usual amount of variation in texture and composition from point to point. It is difficult to conceive of a mass of this size and general uniformity crystallizing under anything like vein conditions. With very high gaseous content and correspondingly high mobility it would be natural to expect more differentiation both in texture and composition. It seems probable that the specific gravity and the viscosity of such a pegmatite magma was not so much below that of a granite mass intruded under similar conditions as has been commonly supposed.

Fragments of the wall-rock are very frequently inclosed by the border portions of the granite masses of Maine. The phenomenon

is much less common in the case of the pegmatites, but was nevertheless observed at several localities. On the highest portion of Streaked Mountain a number of patches of schist a few square yards in area were seen apparently entirely inclosed by pegmatite. Small schist fragments are also inclosed by pegmatite in the Boothbay Harbor region. Dr. W. H. Emmons of the U.S. Geological Survey, who visited Mt. Mica a year later than the writer, when the excavation had proceeded farther, observed schist fragments in the pegmatite there a few feet below the schist hanging wall. These appeared to have been wholly inclosed by pegmatite, and the schistosity of the fragments made large angles with the schistosity of the walls from which they were evidently dislodged. The pegmatite shows no bending of the minerals or other changes in character near the fragments. In the instances cited the schist fragments appear to have been caught up while the pegmatite mass was still partly or wholly fluid, and *the specific gravity of the magma was sufficient, at least in the Mt. Mica example, to float the fragments.*

Temperatures of pegmatite crystallization.—Some evidence in regard to the temperatures of the pegmatites at the time they crystallized has been obtained from studies of quartz by Wright and Larsen,[1] a number of the specimens being collected by the writer from the pegmatites of Maine and other parts of New England.

Studies of these writers and of earlier observers have shown that at about 575° C., quartz undergoes a sudden change from one form of crystal symmetry to another. Wright and Larsen have defined the criteria which may be applied to distinguish the quartz which crystallized below 575° and that which crystallized above that temperature and has undergone reversal in the solid state upon cooling.

No granites of Maine were tested by these experimenters, but thirteen specimens of granite gneisses and quartz porphyries from other regions show as a rule the characters of high-temperature quartz, thus placing their final crystallization above 575° C.

Quartz from a dike of fine-grained pegmatite from one to four feet wide, which intrudes biotite granite near Rumford Falls, is of the high-temperature variety. This dike is typical of many of the

[1] F. E. Wright and E. S. Larsen, "Quartz as a Geologic Thermometer," *Amer. Jour. Sci.*, XXVIII (June, 1909), 423–47.

finer-grained pegmatite bodies of the state. Tests of the quartz from graphic granite in the quarry at Topsham, Maine, and a similar graphic granite collected by the writer from Portland, Conn., also showed high-temperature characteristics. Similar results were obtained with graphic granite from the Urals in Russia.

In contrast to the high temperature of formation indicated by these quartzes, tests upon specimens of rose quartz from the Maine pegmatites and from typical granite pegmatite at Bedford, N.Y.,[1] indicated crystallization at temperatures below 575°. Similar low-temperature characteristics were also exhibited by a sample from a large mass of white quartz from Topsham, Maine. This graded into quartz of graphic granite which when tested showed high-temperature characters. Quartz from a cluster of well-defined crystals occurring in a miarolitic cavity in pegmatite in Topsham showed low-temperature characteristics. This quartz group interlocked at its base with the feldspar of the wall of the pocket and plainly crystallized with the rest of the pegmatite mass. Quartz associated with lepidolite and albite in the gem-bearing portion of pegmatite from Poland, Maine, showed low-temperature characteristics. A pyramid-tipped prism of quartz from Topsham, projecting into a feldspar crystal in the midst of coarse pegmatite and plainly a contemporaneous crystallization, showed low-temperature characteristics. Crystals of smoky quartz from Poland, developed on the walls of pockets, showed low-temperature characteristics.

The results of these tests are consistent among themselves and in accord with the order of crystallization of various portions of the pegmatite established by field evidence. While it is unsafe to draw sweeping conclusions from a rather small number of tests, these are nevertheless highly suggestive, and render it very probable that while many of the finer-grained pegmatite masses crystallized above 575° C., certain portions of the coarser pegmatites crystallized at lower temperatures. In these coarser pegmatites the graphic intergrowths of quartz and feldspar crystallized above 575° C., while the coarser and more siliceous portions characterized by cavities, and probably richer in gaseous or fluid constituents, crystallized below 575°. Since

[1] Edson S. Bastin, "Feldspar and Quartz Deposits of Southeastern New York," *Bull. U.S. Geol. Survey No. 315*, 395–98.

portions showing high- and low-temperature characteristics are frequently intimately associated in the same pegmatite mass, we have here furnished a key to the general temperature of solidification of many of these bodies, namely in the neighborhood of 560–80° C.

Eutectics in pegmatites.—Largely as a result of the extensive studies of Vogt[1] many geologists[2] have been led to attribute an important rôle to eutectics in rock formation. One of the first[3] phenomena to suggest such a relation was obviously the graphic structure exhibited by many pegmatites, which closely resembled patterns formed by eutectic mixture in alloys. Vogt[4] calculated the ratio between quartz and feldspar in a number of analyses of graphic intergrowths of quartz with microcline, the latter mineral being also perthitically intergrown with various amounts of soda plagioclase. The ratios were constant enough to lead Vogt to conclude that the graphic granites represented eutectic mixtures. Slight disparities between analyses he attributed to slight variations in the compositions of the feldspars and to variations in the pressures under which the granites had crystallized. In many cases, especially in microscopic varieties, the graphic intergrowths are considered to be the end-products of crystallization.

In 1905, H. E. Johansson,[5] working mainly with Vogt's analyses, computed the molecular proportions of the quartz and feldspars present and arrived at the conclusion that these bore very simple numerical relations to each other. In graphic granites with dominant orthoclase the molecular ratio of feldspar to quartz was about 2:3. In an oligoclase graphic granite the proportion was about 1:2, and in an albite-quartz micropegmatite about 1:3.

Later Bygden[6] made a considerable number of other analyses of graphic granites with the special purpose of determining to what

[1] Vogt, *Die Silikatschmelzlosungen*, II, 117–35 (1903).

[2] See Harker, *The Natural History of Igneous Rocks*, 262–66, 270–72.

[3] See Teall, *British Petrography*, 401–2 (1888).

[4] *Op. cit.*, 120–21.

[5] H. E. Johansson, *Geologiska föreningens förhandlingar* (Stockholm, 1905), XXVII, 119.

[6] A. Bygden, "Ueber das quantitative Verhältnis zwischen Feldspar und Quartz in Schrift-Graniten," *Bulletin of the Geological Institution of the University of Upsala*, VII, 1–18 (1904–5).

extent the quartz-feldspar ratio is dependent upon the composition of the feldspar. He concluded that the ratio between quartz and feldspar bore no *regular* relationship to the composition of the feldspar. He believed that in most graphic granites definite ratios did exist between the proportions of feldspar and quartz but that these ratios were not always so simple as Vogt and Johansson had supposed.

TABLE SHOWING COMPOSITIONS OF GRAPHIC GRANITES

No.	Locality	Feldspar* Percentage	Quartz* Percentage	Molecular Percentages of Feldspar Components			Reference
				Orthoclase	Albite	Anorthite	
1	Skarpö	70.5	29.5	82.5	15.1	2.4	Bygden No. 7
2	Hitterö	66.0	34.0	77.6	21.6	0.8	Bygden No. 8
3	Voie, Arendal	74.7	25.3	73.8	24.0	2.2	Vogt No. 1
4	Elfkarleö	79.2	20.8	74.8	24.5	0.7	Bygden No. 6
5	Topsham, Me.	72.9	27.1	74.4	25.6	none	Bastin
6	Topsham, Me.	73.7	26.3				
7–8	Hitterö	75.3	24.7	69.1	28.5	2.4	Vogt Nos. 2 and 3
9	Reade	72.7	27.3	66.1	28.2	5.7	Vogt No. 4
10	Arendal	76.5	23.5	63.9	33.7	2.4	Vogt No. 5
11	Bedford, N.Y.	76.8	23.2	61.7	37.0	1.3	Bastin
A	Rödö	56.0	39.0	9.6	85.4	5.0	Bygden No. 9 (Holenquist)
B	Evje	68.3	31.7	12.4	76.0	11.6	Vogt No. 6
C	Ytterby	62.1	37.9	4.3	74.5	21.2	Bygden No. 11
D	Beef Island	81.7	18.3	4.6	68.0	27.4	Bygden No. 12

* Calculated from the analyses.

To supplement the small number of available trustworthy analyses the writer collected specimens of graphic granite from the Fisher feldspar quarry in Topsham, Maine, and from Kinkle's feldspar quarry in Bedford, N.Y. These were analyzed by Mr. Geo. Steiger in the laboratory of the U.S. Geological Survey. In order that the material analyzed should represent closely the true composition about 10-pound samples of the Maine occurrences were taken. These were pulverized, carefully mixed, and quartered down to convenient size for analysis. The New York specimen was a cleavage piece about $2 \times 3 \times 1$ inches in size.

The ratio of quartz to feldspar in the analyses published by Vogt and Bygden and in the author's analyses are given in the table above.

In Fig. 3 the composition of the feldspars are plotted on triangular projection. The numbers on the diagram correspond to those in the table.

From the table and diagram it is at once evident that even among those graphic granites whose feldspars are almost identical in composition (such as Nos. 2 to 6) there are quite considerable variations

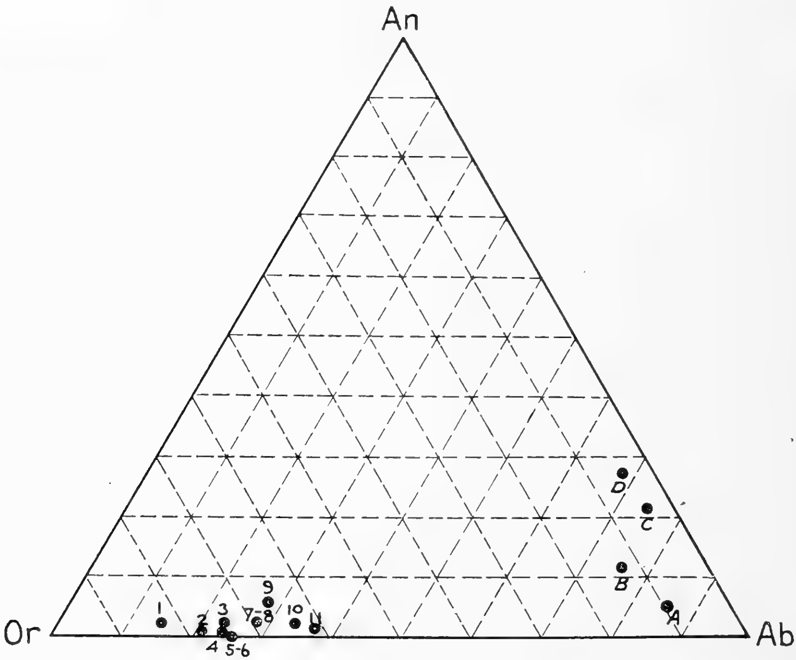


FIG. 3.—Three-component diagram showing the relationships between the molecular percentages of orthoclase, albite, and anorthite in the graphic granites tabulated above. The numbers and letters in table and diagram correspond.

in the quartz-feldspar ratio. In analyses Nos. 1, 2, 3, 7, 8, 10, and 11 (particularly in Nos. 1, 3, 7, 8, and 10) the percentage of anorthite is small and nearly constant, the only important variation being in the ratio between orthoclase and albite. No regular or consistent relationship is recognizable, however, between this ratio and the ratio between quartz and feldspar. The grouping of Nos. 1 to 11 near the lower line of the diagram signifies merely that the feldspar asso-

ciated with the orthoclase (or microcline) in graphic granites as in normal granites[1] is usually albite or oligoclase.

Both analyses and microscopic studies show that most graphic granites are mixtures of three minerals: (1) quartz, (2) orthoclase or microcline, and (3) a member of the isomorphous series of plagioclase feldspars. It should be pointed out moreover that if water or other gases were present, as it is almost certain they were, they formed additional components whose amount the analyses do not reveal but whose influence upon the proportions of the other constituents may have been great. If graphic granites crystallized from magmas of eutectic proportions, these were therefore eutectics of at least four components. *The above series of analyses, though suggesting that the proportions between the constituents of graphic granites are controlled by some laws, can hardly be regarded as proving their eutectic origin.* The theoretical value of such analyses, in elucidating the laws governing rock solutions, is impaired by the fact that they take no account of the gaseous components of the magmas.

Vogt[2] states that in many instances, especially when developed on a microscopic scale, the graphic intergrowths represent the last portions of the magma to crystallize. This fact he cites as in harmony with the conception that they represent eutectic residues. While this may be the true relation in some cases, in other cases the graphic granite was unquestionably not the last crystallization from the magma. In the Fisher feldspar quarry in Topsham, for example, where large masses of graphic granite pass gradually and irregularly into large areas of pure quartz and feldspar, the tests of Wright and Larsen (see p. 310) have shown that the quartz of the graphic intergrowths crystallized above 575° C., whereas the quartz of the large pure areas crystallized below 575°. The latter was therefore the later crystallization. The gem and cavity-bearing portions of the Maine pegmatites in almost every instance grade gradually into normal pegmatite containing abundant graphic granite. From the presence of cavities and of the rare minerals, from the general field relations, and from the fact that the quartz of the pockets and the gem-bearing portions wherever tested is of the low-temperature variety, there can

[1] See Clarke, "The Data of Geochemistry," *Bull. U.S. Geol. Survey No. 330*, 369.

[2] *Op. cit.*, 118.

be no reasonable doubt that these gem- and cavity-bearing portions rather than the adjacent graphic portions were the last parts of the pegmatite to crystallize.[1]

In considering the significance of the graphic intergrowths found in pegmatite it is necessary to consider not only the intergrowths of feldspar and quartz but also the almost equally regular intergrowths of muscovite and quartz, garnet and quartz, black tourmaline and quartz, etc. Since muscovite, tourmaline and garnet are less abundant in the pegmatites than feldspar, their intergrowths with quartz are also less abundant and usually of smaller size. Such intergrowths occur, however, scattered irregularly through practically all of the coarser pegmatite masses. If we adopt the usual conception of the eutectic as the residue of uniform composition and minimum freezing-point which is the last portion to crystallize, it is manifestly impossible to regard each of these intergrowths as representing a eutectic mixture, unless indeed several portions of the pegmatite magma are regarded as crystallizing more or less independently of the remainder of the mass.

Mineralogical provinces.—Most of the known pegmatites of Maine which are rich in sodium and lithium minerals, that is, the gem-bearing pegmatites, are restricted to a zone about twenty-five miles long and eight to nine miles in width extending in a northwesterly direction from Auburn in Androscoggin County to Greenwood in Oxford County. A second and much smaller area includes the Newry and Black Mountain localities in the northern part of Oxford County and differs from the larger area in that the gem minerals occur imbedded in the solid pegmatite and not in pockets. Within both areas the lithium-bearing phases form only a small proportion of the pegmatite present, most of which has the normal composition. The presence locally of certain masses of unusual composition is to be attributed either to a very minute excess of sodium and lithium

[1] In the tourmaline-bearing pegmatites of California, according to Mr. W. T. Schaller (oral communication), the zones characterized by cavities and by the presence of the gems and other rare minerals, which were almost certainly the last portions to crystallize, grade laterally without sharp break into graphic granite which borders one wall of these pegmatite masses. Occasional stringers of pegmatite bearing lithium minerals branch off from the main gem-bearing layer and cut the bordering graphic granite.

throughout the magma which gave rise to these pegmatites, over the percentages in bordering pegmatite magmas, or else to differing degrees of magmatic segregation in magmas whose average composition was similar. As already explained, quartz associated with lepidolite and clevelandite from the gem-bearing portion of one of these pegmatites showed low-temperature characters, and the unusual abundance of pockets indicates that these portions were richer than the normal in gaseous constituents, probably mainly water vapor. In general therefore the gem-bearing pegmatites were characterized by a higher percentage of sodium, lithium, and phosphorus than the normal pegmatites, and probably by more water vapor and a slightly lower temperature of crystallization.

The region characterized by pegmatites rich in fluorine minerals but not in the lithium minerals forms an area only a few miles across in the town of Stoneham and bordering parts of other towns in Oxford County and the town of Chatham, New Hampshire.

Bearing of broad geologic relations on genesis.—The broad geographic relationships of the granites and pegmatites are also significant of their relationship and origin. Many of the granite areas of the eastern portion of Maine are characterized by sharp boundaries, while most of the granite areas of southwestern Maine show very indefinite boundaries and are bordered by large areas of slates and schists which have been intruded by various amounts of granite-gneiss and pegmatite and by some granite and diorite. The contrast between the two types of contacts is well shown within the areas of the Penobscot Bay[1] and Rockland[2] folios. In many parts of the latter area, notably along the granite-schist contact from Bluehill village northward and from Bluehill Falls southwestward to Sedgwick, the granite preserves its normal medium grain up to the exact contact. In most places this contact is so sharp that it is possible to stand with one foot resting upon typical Ellsworth schist and the other foot resting on normal granite. Dikes and irregular intrusions of granite are not very abundant in the schists near the main granite masses, and flow-gneiss, pegmatite, and basic differentiations from the granite magma are almost entirely absent. In the Rockland quadrangle,

[1] *Geologic Atlas U.S.*, folio No. 149, U.S. Geol. Survey.

[2] *Ibid.*, folio No. 158.

on the other hand, the contact relations are wholly different, the change from pure granite to pure sediments taking place gradually through a transition zone of contact metamorphosed and injected sediments two to three miles in width. These transition zones include a great variety of rocks, slate, schist, injection gneiss, flow-gneiss, diorite, diabase, pegmatite, and granites of various textures, all associated in the most irregular manner so that it is impracticable to delineate them separately in ordinary geologic mapping. In western and southwestern Maine these transition zones are much broader than in the Rockland quadrangle and contain larger amounts of pegmatite and granite gneiss and smaller amounts of basic igneous rocks.

The contrast between the sharpness of certain granite contacts observed in the Bluehill region and the very gradual transitions observed in the Rockland quadrangle and farther southwest seem to be best explained on the hypothesis that the broad injected zones represent portions of the "roof" of granite batholiths, whereas the sharp contacts represent the sides of similar batholiths. The character of the rocks which are found in the two types of contacts lends support to this view. The more ready escape of water gas and other gases and their dissolved substances upward than laterally may explain the great abundance of pegmatite in the broad transition zones, inasmuch as the presence of such gases is believed to be the most important factor in the development of pegmatitic texture. It is a reasonable supposition that basic differentiation from the granitic magma would also be more rapid upward than laterally, and the abundance of diabase and diorite in certain of the transition zones may thus be accounted for. The hypothesis is also in accord with the low temperatures at which certain portions of the pegmatites appear to have crystallized, in comparison with the temperatures of crystallization of normal granites, and accords with the presence of numerous dikes of very fine-grained granite, some so fine as to be rhyolitic, in certain of the contact zones, and their absence about the sharper contacts.

Summary.—Field and laboratory studies of the Maine pegmatites indicate that all are in a broad way contemporaneous and are genetically related to the associated granites.

External conditions, though locally having some slight influence,

are not primarily responsible for the pegmatitic textures. The presence of the rarer elements seems to have had only a minor influence on the texture since in many typical pegmatites such elements appear entirely absent. Theoretical considerations and the presence of miarolitic cavities in certain pegmatites point to the gaseous constituents of the pegmatite magmas, especially water vapor, as the primary cause of their textures.

While certain facts, such as the pinch and swell phenomena observed in many pegmatite dikes in contrast with the parallel-walled character of most of the granite dikes, indicate somewhat greater mobility in the pegmatite than in the granite magmas, other facts, such as the sharpness of many of the contacts between pegmatite and schist, the absence of absorption along any of the contacts, the presence of angular schist fragments now surrounded by pegmatite, the small proportion by volume which the cavities bear to the whole pegmatite mass, the absence of notably greater contact metamorphic effects near pegmatite than near granite contacts, and the batholithic dimensions of some pegmatite bodies, all suggest that the difference in average composition between the granite pegmatites and the normal granites was perhaps not so great as has generally been supposed.

In his textbook on *Igneous Rocks* Iddings[1] in discussing the pegmatites says: "The amount of gases concentrated in such magmas was not many times that of the gases originally distributed throughout the magma from which the pegmatite was differentiated; possibly not more than ten times as much." The present writer would be inclined, in the case at least of the granite pegmatites of New England, to limit the gaseous content of these rocks still further.

The experiments of Messrs. Wright and Larsen on quartz from pegmatites from Maine and elsewhere indicate that some at least of the coarser pegmatites began to crystallize at a temperature slightly above the inversion-point of quartz (about 575° C.) and completed their crystallization somewhat below this temperature. It is probable that many of the finer-grained pegmatites crystallized wholly above 575° C.

The theory that the graphic intergrowths in pegmatites represent eutectic mixtures cannot be regarded as proven by the published

[1] Joseph P. Iddings, *Igneous Rocks* (1909), I, 276.

analyses. Certain field evidence is unfavorable to the theory that these are eutectics.

The broader field relations suggest that the large areas characterized by particular abundance of pegmatite intrusions constitute in reality the *roofs* overlying granite batholiths. Where more extensive erosion has exposed the flanks of such batholiths pegmatite masses in the bordering schists are not abundant.

THE SOLUTION OF GOLD IN THE SURFACE ALTERATIONS OF ORE BODIES

ALBERT D. BROKAW

The leaching of gold from the outcrop of auriferous lodes has been the subject of much discussion, and many contradictory statements regarding the chemistry involved have arisen in the literature. Frequently these statements are based on experimental evidence, and the contradictions may be explained, in part at least, by a lack of uniformity in the conditions under which the experiments were carried out, and a tendency to ignore the conditions of temperature and concentration of solution that we are justified in supposing to be operative in the surface alteration of such deposits.

Clarke[1] has summarized the natural solvents for gold as reported by various observers. Their experiments, however, have been made under such a diversity of conditions that the results are not an adequate basis for comparisons, and it seemed desirable to ascertain where the emphasis should be placed in discussing this phase of the natural solution of gold.

At the suggestion of Professor W. H. Emmons, the writer undertook a series of experiments with a view of determining which of the various solvents noted are most effective in the solution of gold. By limiting the problem to alteration many substances are eliminated; only such as are known to occur in mine waters or in the gossan were studied, and the concentrations used are comparable to those shown by mine waters. The experiments were carried on at room temperature (18° to 25°), as Stokes[2] has shown that elevated temperatures have a very marked influence on the solubility of gold in ferric salt solutions.

A few of the solvents suggested by Don, Rickard, Lenher, and others were made the subject of a comparative study, the conditions of temperature and concentration being practically uniform for the

[1] Clarke, *U.S.G.S. Bull. 330*, 557.

[2] Stokes, *Econ. Geol.*, I, 650.

series. The substances studied were ferric sulphate, ferric chloride, sulphuric acid, hydrochloric acid, and manganese dioxide. These were covered by the following experiments, each in duplicate. Solution of gold is shown by loss of weight.

1. $Fe_2(SO_4)_3+H_2SO_4+Au$
   (*a*) no weighable loss.
   (*b*) " " "
2. $Fe_2(SO_4)_3+H_2SO_4+MnO_2+Au$
   (*a*) no weighable loss.
   (*b*) .00017 g. loss.[1]
3. $FeCl_3+HCl+Au$
   (*a*) no weighable loss.
   (*b*) " " "
4. $FeCl_3+HCl+MnO_2+Au$
   (*a*) .01640 g. loss. Area of plate 383 sq. mm.
   (*b*) .01502 g. " " " " 348 " "

The solutions were tenth normal[2] with respect to ferric salt and to acid. In each duplicate 50 c.c. were used. In experiments 2 and 4, 1 g. of powdered manganese dioxide was added to each duplicate. The gold was obtained from Goldschmidt Bros. and assayed 99.9 per cent pure. It was rolled to a thickness of about .002 in., and cut into pieces of about 350 sq. mm. area, and one piece, weighing about 0.15 g., was used in each duplicate. The gold was washed with alcohol and ether and dried, then each piece was carefully weighed. The experiments were carried on in tightly stoppered test-tubes which were thoroughly shaken from time to time. After two weeks the pieces of gold were removed by means of a platinum wire, and washed with water, alcohol, and ether, in turn, before weighing. In experiments 2 and 4 a small amount of manganese dioxide adhering to the plates was removed by means of a solution of ferrous sulphate acidified with sulphuric acid, after which the plates were treated as above. At the end of two weeks all but experiment 4 gave negative results when weighings were made to 0.0001 g., and the balance was ex-

[1] This duplicate was found to contain a trace of Cl which probably accounts for the loss.

[2] Normal as used in this paper refers to "equivalent normal" solutions. Tenth normal concentration was selected rather arbitrarily except for the fact that it is well within the range of concentration shown by mine waters. (See table of analyses, p. 326.)

changed for one sensitive to 0.00001 g. which was used from that time on. The whole time was 34 days. In experiment 4 it will be seen that the losses in (*a*) and (*b*) are approximately proportional to the areas of the plates.

The results of these experiments, as given above, show conclusively that, of the conditions under consideration, the most favorable for the solution of gold involve the presence of manganese dioxide and chlorides. Although it is frequently stated that gold is readily soluble in ferric sulphate solutions,[1] no loss of gold was detected after 34 days' contact with a tenth normal solution of that salt.[2]

In order to reproduce more nearly the conditions in nature experiment 5 was prepared as follows: a solution was made N/10 with respect to ferric sulphate and sulphuric acid, and N/25 with respect to sodium chloride. To 50 c.c. of solution 1 g. of powdered manganese dioxide was added and the experiment was carried on as before.[3] The loss is comparable to that found in experiment 4,

5. $Fe_2(SO_4)_3+H_2SO_4+NaCl+MnO_2+Au$
Loss of Au .00505 g. Time 14 days.

allowing for the shorter time and the greater dilution of the chloride. The same experiment without MnO_2 showed no loss of gold.

After it had been shown that chlorides and manganese dioxide were necessary under these conditions, the next point to be determined was whether the free acid or the ferric chloride is the active agent in bringing about the solution. In experiment 6, 50 c.c. of N/10 HCl was used with 1 g. of powdered MnO_2. In experiment 7, sodium hydroxide was added to 50 c.c. of N/10 ferric chloride solution until the precipitate formed barely redissolved on shaking,[4] after which 1 g. of powdered MnO_2 was added.

6. $HCl+MnO_2+Au$
Loss of Au .01369 g. Time 14 days.

7. $FeCl_3+MnO_2+Au$
Loss of Au .00062 g. Time 14 days.

[1] E.g., *Genesis of Ore Deposits*, 478, 481, and elsewhere.

[2] This agrees with Stokes, *loc. cit.*

[3] This is essentially the experiment of Rickard, *Trans. A.I.M.E.*, XXVI, 798. From experiments 6 and 7 it appears that the ferric salt is unnecessary.

[4] Even then the solution was somewhat acid owing to the hydrolysis of the ferric chloride.

The experiments were conducted as before. The results show clearly that the free acid, rather than the ferric chloride, in the presence of manganese dioxide exercises the great solvent action, as the same amount of chlorine was present in both cases. Essentially, the most favorable conditions for the solution of gold are those in which free chlorine may be liberated.

W. J. McCaughey,[1] in studying the solubility of gold in ferric salt solutions, found that ferrous sulphate, even in very small amounts, had a marked effect in depressing the solubility of gold. Conceivably this may be a factor to be considered, and with this in view experiment 8 was performed, to determine whether ferrous sulphate, in the presence of sulphuric acid and manganese dioxide, would be quickly oxidized to the ferric salt, according to the following equation:

8. $2FeSO+2H_2SO_4+MnO_2=Fe_2(SO_4)_3+MnSO_4+2H_2O$

After acidifying 100 c.c. of 1.6 N. $FeSO_4$ solution with sulphuric acid, it was shaken vigorously with 5 g. of powdered MnO_2. After five minutes the solution was filtered off. No ferrous iron was detected by the ferricyanide test, showing that the iron had been completely oxidized to the ferric state. The experiments were not done in such a way that the velocity of the oxidation could be measured, but the result shows that ferrous sulphate in acid solution is quickly oxidized by manganese dioxide, hence the suppression of the solution of gold by ferrous salts may be disregarded if manganese dioxide is present. It is interesting to note in this connection that the analysis of a sample of water from the Comstock Lode,[2] showing the greatest amount of ferric iron, showed a considerable amount of manganese, but no ferrous iron; a condition exactly in accord with the right-hand side of the above equation.

McCaughey's experiments on the solubility of gold in ferric salt solutions were made with stronger solutions than are known to occur in mine waters, but his results show that gold is attacked by ferric salts in the presence of hydrochloric acid.[3] While no loss of gold

[1] McCaughey, *Jour. Am. Chem. Soc.*, XXXI, 1269.

[2] See analysis 3, p. 326. Nos. 5 and 6 illustrate the same fact.

[3] If gold is dissolved by ferric chloride the reaction might be expected to be as follows:

$$Au+3FeCl_3=AuCl_3+3FeCl_2$$

This would seem to be a reversible action, as ferrous salts are commonly used as a pre-

was noted in experiment 3 as carried out by the writer, it is possible that in a longer time some loss might be detected, as more dilute solutions act more slowly.

SUMMARY

From the above experiments it appears:

1. That at the dilution of natural solutions of ferric salts their solvent effect on gold is probably very slight;

2. That in the presence of manganese dioxide no increased solubility is found unless chlorides are present;[1]

3. That mixtures of ferric sulphate, sulphuric acid, and sodium chloride in concentrations common in mine waters will readily dissolve gold in the presence of manganese dioxide;

4. That free hydrochloric acid in the presence of manganese dioxide has a much greater solvent effect than the same amount of chlorine in ferric chloride solution;

cipitant for gold. McCaughey, however (*op. cit.*, footnote, p. 1270), failed to detect any ferrous salt after the action had gone on for two days. It seemed probable that ferrous chloride had been formed, but was oxidized by contact with the air. Accordingly the experiment was repeated in an atmosphere of carbon dioxide, care being taken to exclude, as far as possible, all contact with the air. Several possible sources of error were not eliminated and the experiment is only of preliminary nature. The results were as follows:

	Loss of Gold	Weight of Ferrous Iron	
		Observed	Calculated
(*a*)...	0.02904	0.0240	0.02476
(*b*)...	0.03247	0.0282	0.02769

This seems to establish the correctness of the equation given above. The result is not in accord with the statement of McIlhiney (*Am. Jour. Sci.*, Ser. IV, II, 293) who found that gold dissolved in ferric chloride only in presence of air. The greater dilution at which he worked may account for this.

[1] The influence of manganese compounds in chemical reactions involving oxidation is noted in many cases. E.g., Moissan (*Chim. Minerale*, V, 617) states that fuming hydrochloric acid in presence of air will dissolve gold, especially if manganous chloride is present. The catalytic action of manganese dioxide in the decomposition of potassium chlorate and hydrogen peroxide are well known. Probably manganese compounds are of considerable importance in natural oxidations, even though they may be present in very small amounts.

5. That the influence of ferrous salts in suppressing the solubility of gold is negligible if manganese dioxide is present;

6. That the solution of gold is practically limited to the oxidized zone.

In agreement with these experiments is the fact that manganiferous lodes bearing pyrite, in areas of chloride waters, are leached to greater depths than lodes that do not carry manganese.[1]

In conclusion, the writer wishes to thank Professor Emmons for his suggestions and advice in the conduct of the work, and Messrs. C. Russell and N. Sankowsky for placing at his disposal an unpublished tabulation of mine waters which they have assembled. Six complete analyses of vadose waters from their tables are appended:

	1*	2†	3‡	4§	5¶	6¶
Cl	12.40	186.40	127.60	19.00	tr.	tr.
SO_4	124.80	161.70	209100.00	474.00	258.40	26.55
CO_3	......	1513.44	....	20.45	......	.....
NO_3	......	1.60	....	......	......	.....
PO_4	......	tr.	....	......	......	.....
K	......	198.00	....	53.40	......	.....
Na	......	719.45	535.00	132.00	......	.....
Li	......	2.85	....	......	......	.....
Ca	46.40	146.41	1286.00	100.100	121.40	72.48
Sr	......	1.95	....	......	......	.....
Mg	14.50	177.67	6590.00	5.88	13.08	14.90
Al	......	1.06	9760.00	1.37	1.49	0.37
Mn	......	0.57	885.10	......	4.72	4.12
Ni	......	......	....	......	tr.	tr.
Co	......	......	....	......	tr.	tr.
Cu	......	0.02	147.50	......	......	.....
Zn	8.90	0.34	....	......	2.82	47.40
Pb	......	1.35	....	......	......	.....
SiO_2	18.00	24.42	616.00	133.40	2.10	8.00
Fe^{++}	6.60	3.50	....	......	......	.....
Fe^{+++}			5025.00	6.33	4.74	6.30

* *U.S.G.S. Bull. 330*, 547.

† *Ibid.*

‡ *Bull. Univ. of Cal.*, IV, 192.

§ *Ibid.*, 189.

¶ Beck, *Nature of Ore Deposits* (Weed), II, 377. Analyses expressed in milligrams per liter. Where necessary they have been recast.

MARCH, 1910

[1] See W. H. Emmons, *Min. and Sci. Press*, December 11, 1909.

EARTHQUAKES IN BRAZIL

J. C. BRANNER

Earthquakes are so rare in Brazil that their very rarity is a matter of interest to geologists and seismologists. In order to give an idea of the low seismicity of that country and to facilitate the collection and preservation of data in the future I have brought together in this paper all the information it has been possible to gather from a considerable acquaintance with the literature of Brazilian geology.

In January, 1909, Dr. M. A. R. Lisboa of Petropolis, a distinguished Brazilian geologist, published in the *Jornal do Commercio* of Rio de Janeiro a résumé of Brazilian earthquakes that is the most complete list thus far printed. That paper, however, is not accessible to geologists and seismologists, and I have been able to make several additions to the list.[1]

The table gives all the reported earthquakes in their chronological order, and one column shows the intensities by the Rossi-Forel scale as nearly as they can be judged from the accounts.

The papers cited include all the known publications regarding earthquakes in Brazil. There is one important article, however, bearing upon seismology in Brazil that has not been used in constructing the table, and that is a paper containing a list of eathquake shocks reported at sea off the northeast coast of Brazil by sailing masters. That article is entitled "Note sur l'existence probable d'un volcan sou-marin situé par environ 0° 20′ de latitude sud, et 22° de longitude ouest," par P. Daussy, *Comptes Rendus*, VI, 512–18 (Paris, 1838).

In his "Tremblements de Terre," *Géographie Séismologique*, M. Montessus de Ballore gives a chart of the region at p. 168.

1. *Manoel Ayres de Cazal.*—Corografia Brazilica, ou relação historico-geografica do Reino do Brazil, I, 261. Rio de Janeiro, 1817.

In his description of the province of Matto Grosso the author has this note on earthquakes: "On the 24th of September (1744) at noon, during clear weather, underground thunder was heard, and immediately the earth trembled, giving

[1] See reference No. 14 below.

several rockings that caused great alarm everywhere in Matto Grosso and Cuyabá. . . . . The earthquake that shook the Kingdom of Peru and destroyed the city

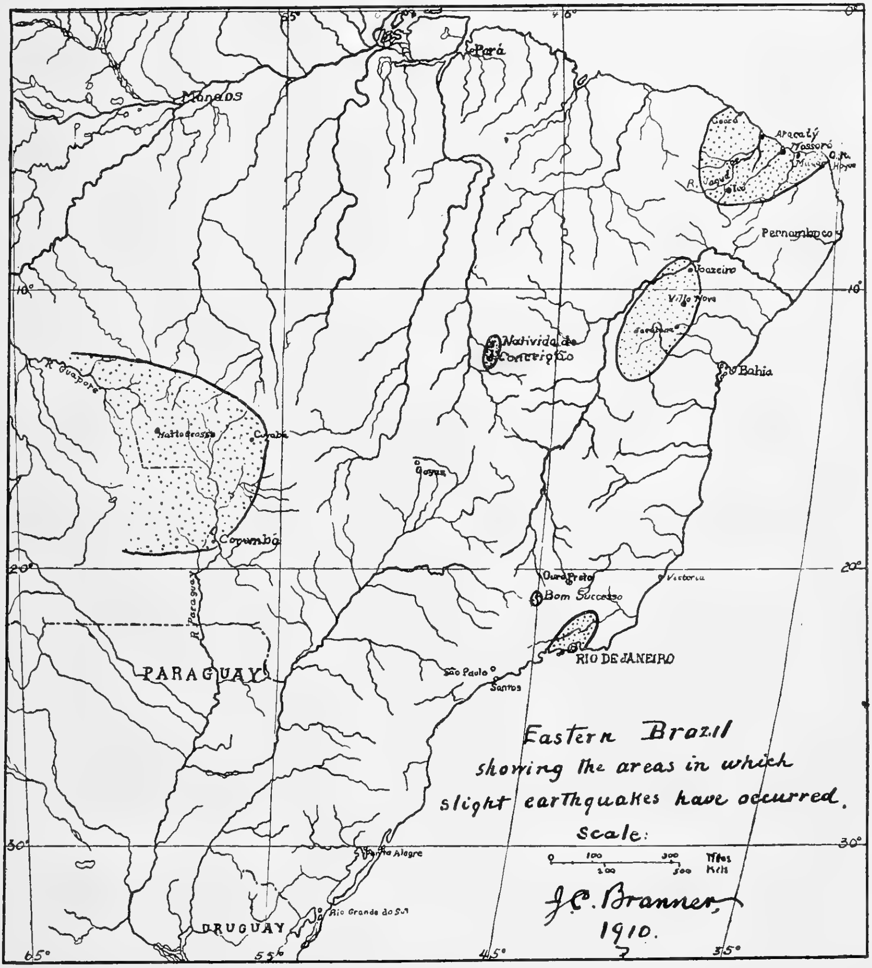
TABLE OF EARTHQUAKES REPORTED IN BRAZIL

Figures on the right refer to the authorities following the table

Year and Date	State	Locality	Intensity (Rossi-Forel)	Authority
1744, Sept. 24	Matto Grosso	Cuyabá, etc.	VI	Cazal, 1
1746, Oct. 28	Matto Grosso	Matto Grosso	V	Cazal, 1
1767 (9?), Aug. 1	Espirito Santo	....	......	Capanema, 2
1807, Aug. 8	Ceará	Jaguaribe Valley	......	Pompeo de Souza, 3
1810, May 31	Ceará	Granja	......	Pompeo de Souza, 3
1811, Oct. 28	Pernambuco	Recife	VI	Dom Pedro, II, 4
1812 (13?)	Rio Grande do Sul	Porto Alegre	......	Capanema, 2
1824	Ceará	Jardim	VIII–IX?	Pompeo de Souza, 3
1824	Minas Geraes	Caximbú, etc.	VI	Massena, 5
1826	Goyaz	Natividade Conceição	IV–V	Gardner, 6
1832, Sept. 18	Matto Grosso	Principe da Beira	......	Fonseca, 7
1834	Goyaz	Natividade Conceição	IV–V	Gardner, 6
1846	Ceará	Granja	......	Pompeo de Souza, 3
1852, Dec. 2	Ceará	Aracatý	......	Capanema, 2
1852	Ceará	Granja	......	Pompeo de Souza, 3
1854, Jan. 10	Rio Grande do Norte	Touros	......	Capanema, 2
1855	Ceará	Granja	......	Pompeo de Souza, 3
1860, Oct. 1	Matto Grosso	....	......	Fonseca, 7
1861, June	Rio de Janeiro	Paratý, etc.	IV–V	Massena, 5
1867, Several	Minas Geraes	Jaguára	IV	Burton, 8
1876, June 26	Matto Grosso	N. of Corumbá	IV	Fonseca, 7
1886, May 9	Rio de Janeiro	Petropolis, Rio S. Paulo, Minas	V	Dom Pedro II, 9 Cruls, 10
1901, April 4 1901, April 5 1901, July 1 1901, Sept. 4	Minas Geraes	Bom Successo	IV	Silveira, 4
1905, July 18	Bahia	Bomfim to Joazeiro	IV–V	Silva, 12 Branner, 14
1906, Nov.	Matto Grosso	Miranda Coimbra Corumbá, etc.	IV–V	Lisboa, 13

of Lima in October, 1746, was clearly felt here; but it only frightened a few of the inhabitants."

It should be noted that Dr. Fonseca mentions an earthquake in Matto Grosso on September 24, 1749. It seems probable that there is some confusion in regard to the year. See reference 7 below.



2. *G. S. de Capanema.*—Quaes às tradições, ou vestigios geologicos que nos levam a certeza de ter havido terremotes no Brazil. Revista do Instituto Historico, XXII, 135–59, Rio de Janeiro, 1859. (Read November 24, 1854.)

Barão de Capanema wrote to the presidents of all the Brazilian provinces for information regarding earthquakes; after three years, no replies having been received, the request was renewed by the Instituto Historico e Geographico, and to these later inquiries six of the presidents replied, but apparently most of them gave negative results. The paper contains reference to some phenomena that may or may not indicate earthquakes. Capanema's list includes the two mentioned by Ayres de Cazal in Matto Grosso, and some of those given later and a little more at length by Thomaz Pompeo de Souza for Ceará. He adds one for Espirito Santo, and one for Rio Grande do Sul. The paper is occupied chiefly with a discussion of earthquakes in general.

3. *Thomaz Pompeo de Souza Brasil.*—Ensaio estatistico da provincia do Ceará, I, 51 (Ceará), 1863. Under the head of "earthquakes" the author states that a few slight shocks have been felt in the valley of the Rio Jaguaribe and at Granja, north of Fortaleza. The important footnote is here given at length:

"The following are the earthquakes of which I have been informed: On August 8, 1807, throughout the entire valley of the Jaguaribe extending northward to Fortaleza (180 kilometers), southward to Icó (300 kilometers), and eastward to Mossoró and the Serra do Martins in the province of Rio Grande do Norte.

"On May 31, 1810, at Granja, and again in the years 1846, 1852, and 1855.

"In 1824 the earth opened making a wide crack from the base of the Serra de S. Pedro to Jardim, a distance of 5 leagues, with a width of about one palm and of unknown depth.

"On December 2, 1852, at Aracatý."

4. *Dom Pedro d'Alcantara.*—Documentos relativos ao tremor de terra havido em Pernambuco em 1811. Revista do Instituto Historico e Geographico, XXIII, 401–6. Rio de Janeiro, 1860.

The date and intensity of an earthquake felt at Pernambuco October 28, 1811, are fixed by three letters written by observers in reply to inquiries made by the Emperor Dom Pedro II. One observer states that the people were filled with terror; another reports that the shock was so violent that things were nearly thrown from tables, and a fountain erected in the patio of one of the churches was overthrown. This suggests an intensity of about VI of the Rossi-Forel scale.

5. *José Franklin da Silva Massena.*—Investigaç˜es scientificas para o progresso da geologia mineira. Revista do Instituto Historico e Geographico, XLVII, 249–82. Rio de Janeiro, 1884.

This is a long article devoted to geology, but at p. 281 the following mention is made of two earthquakes:

"The earthquake of Parati in June, 1861, was quick and oscillating, and was felt in Areias and along the coast, and even at Itajubá.

"The earthquake of 1824 extended from Caximbú to Picú and was felt in the open country. Though the movements were not sufficient to kill persons or animals or to crack the earth, buildings suffered and men felt a dull, quick, rocking shock."

6. *George Gardner*, the English botanist who traveled through Goyaz in 1840, has the following in his Travels in the Interior of Brazil, etc., London (1846), 350:

"Within the last twenty years, two slight earthquakes have been felt both at Natividade and Conceição; the first occurred in the year 1826, and the other in 1834; the movement of the earth was very perceptibly felt in both places, although they were each of short duration. These were the only places in Brazil where I could learn such phenomena had been observed."

7. *João Severiano da Fonseca.*—Viagem ao redor do Brasil (1875–78), I, 198. Rio de Janeiro, 1880.

This writer, in speaking of the province of Matto Grosso, has the following upon earthquakes:

"The annals of the senate of the chambers of Cuyabá mention an earthquake on September 24, 1749, preceded by a loud noise like subterranean thunder.

"On one of the walls of the prison at fort Principe da Beira on the Guaporé I found the following inscription made there by a prisoner with the point of a style. 'On the 18th of September at two o'clock in the afternoon the earth trembled, 1832.'

"Another earthquake is registered on October 1, 1860.

"On June 26, 1876, at about half-past nine at night, while at the fazenda Cambára near the margin of the Rio Paraguay with the other members of the boundary commission, we felt a sharp shock as we lay in our hammocks and beds, and at the same time there was a rattling of the tiles of the roof as if caused by hail, the whole lasting only a few seconds."

The last-mentioned place is between the city of Corumbá and the mouth of Rio S. Lourenço.

8. *Richard F. Burton.*—The Highlands of the (*sic*) Brazil, II, 30. London, 1869.

The author, when near Jaguára in Minas Geraes, made this note in August, 1867: "Sr. Leite, an intelligent store-keeper at the Quinta, which is about half a mile from the River, assured me that the ground had lately been subject to shocks, which were most frequent about full moon."

9. *Dom Pedro d'Alcantara.*—Tremblement de terre survenu au Brésil le 9 mai 1886. Comptes Rendus, CII, 1351–52. Paris, 1886. Also in Nature, XXXIV, 1887–88. London, 1886.

This is a letter from the Emperor Dom Pedro II to M Daubrée, reporting a shock felt at Petropolis at 3:20 P.M. on the date mentioned. He notes the rattling of windows, and that the shock continued about four seconds. He reports the general area over which the shock was felt; it amounts to about 25,000 square kilometers.

10. *M. Cruls.*—Tremblement de terre au Brésil. Comptes Rendus, CII, 1383–84. Paris, 1886.

The shock described by M. Cruls, late director of the astronomical observatory at Rio de Janeiro, is the same as that reported to the French Academy by Dom Pedro II. He says it occurred at Rio de Janeiro, May 9, 1886, between 3 and 3:30 P.M., that it lasted from a few seconds to a minute, and was felt in the provinces of Rio de Janeiro, São Paulo, and Minas over an area about 250 kilometers long by 110 kilometers wide, with its longer axis lying N. 60° E.

11. *Alvaro A. da Silveira.*—Os tremores de terra em Bom Successo, Minas Geraes, Bello Horizonte, 1906. Originally published in Minas Geraes, the official organ, at Bello Horizonte, November 1, 1901.

An earthquake occurred at Bom Successo in the southern part of the state of Minas Geraes on April 4, 1901. The governor of the state appointed Sr. Alvaro A. da Silveira to collect information in regard to it. His official report along with other articles that were puulished on the same subject are brought together in a brochure of 137 pages. The following are the matters of chief interest:

The first shock that was noticed occurred at 1 P.M., April 4, 1901; it was strong enough to rattle dishes, and was accompanied by a rumbling noise.

April 5 at 5 A.M. there was a similar shock.

Subterranean sounds continued to be heard during the months of April, May, and June.

July 1 at 11 P.M. there was a strong shock, and subterranean sounds continued to be heard through July and August. During the latter half of August no sounds were heard.

September 4 at 6 P.M. a sharp shock was felt, about like that of April 4, and people left their houses. During the rest of September and during the first half of October sounds like distant thunder were occasionally heard. Between the 9th and the 15th of October there was but one rather loud rumbling; the others were all small.

He repeats that there were barely four shocks in all; that they caused no damage whatever, even to houses whose walls might easily have been thrown down.

12. *Lourenço Pereira da Silva.*—O municipio do Bomfim. Bahia, 1906, p. 37.

This is a small book of 85 pages 12° describing the natural features of the municipality of Bomfim, formerly known as Villa Nova da Rainha, in the state of Bahia. At p. 37 he says: "It must be still remembered by everyone that an earthquake shock was felt in July, 1904, throughout the zone between Bomfim and Joazeiro. It consisted of a dull rumbling followed by a slight shaking of the earth causing the rattling of dishes and bottles on the shelves of stores, while in homes ornaments and even bird cages were thrown down."

13. *Arrojado Lisboa.*—Tremores de terra no Brasil. Jornal do Commercio. Rio de Janeiro, January 23 (?), 1909.

This is part of a long article on the general subject of earthquakes, ending with a section on earthquakes in Brazil. The copy kindly sent me by Dr. Lisboa is a clipping from the daily paper in which it was printed, and does not contain the date of its publication. The article itself is dated January 22, 1909. The author mentions most of the cases in the table given herewith, and adds information gathered by himself in the state of Matto Grosso in 1908.

He concludes that the following regions in Brazil are periodically affected by earthquakes:

1. Bom Successo district in Minas Geraes.
2. State of Rio de Janiero.
3. Aracatý-Assú region in Ceará and Rio Grande de Norte.
4. The southern portion of Matto Grosso.

He mentions the seismograph in the observatory at Rio de Janeiro and urges the importance of the establishment of three additional stations under the direction of the astronomical observatory as follows: at Aracatý in Ceará or at Macáo or Mossoró in Rio Grande do Norte; at Porto Murtinho, Corumbá, or Miranda, in Matto Grosso, and a third at Bom Successo in Minas Geraes.

14. *Notes by J. C. Branner.*—While traveling through the interior of the state of Bahia in 1907 I found that a slight earthquake had been felt over a considerable area in that region in the year 1905, and the following notes were gathered in regard to it:

There is uncertainty about the year. Some of the persons with whom I talked about it stated positively that it occurred July 18, 1905. Sr. Lourenço Pereira da Silva, quoted above, says it was in 1906, but he does not mention the day of the month.

It was felt by some people, but not by all, at and about the city of Bomfim, where window shutters and bottles on drugstore shelves rattled.

At fazenda Cambão, on the west side of the Salitre Valley, the shock occurred about 8 P.M. and was accompanied by a distant rumbling sound. A man lying in

a hammock reports that it felt as if someone were jerking the cords of his hammock. The iron stirrups of saddles hanging against a wall were rattled together.

At Moita on the fazenda Ingazeira, west side of the Salitre Valley, the shock occurred between 7 and 8 P.M. Hammocks swung, dishes and pans rattled. Similar disturbances were felt at Retiro on the upper part of Rio Ingazeira.

It was felt by many, but not by all, at the city of Morro do Chapeo. A priest lying in a hammock noted that it began to swing; in the shops the bottles on the shelves rattled against each other; a partly opened door slammed; a man leaning against the wall of a house felt it give way and thought it about to fall.

The limits of the area affected were not determined with any clearness. It was not felt at all at Alagoinhas or Aramarý, but it was not ascertained certainly whether it was noticed at Serrinha or Queimadas. It has not been possible to find out whether it was felt north and west of the Rio S. Francisco. The outlines of the area affected are shown on the accompanying map as nearly as present knowledge permits.

The other two areas shown on the map are that about Rio de Janeiro, suggested by the data furnished by Dom Pedro II (reference 9), and the one suggested by the notes of Senator Pompeo de Souza (reference 3).

The Matto Grosso area is represented as extending westward indefinitely. It is so shown because it is assumed that the slight earthquakes that have been felt in that region originate in the Andean country to the west.

The following notes of negative value are not without interest:

A. Collie.—Geological Observations on the Neighbourhood of Rio de Janeiro. Capt. F. W. Beechey's Narrative of a Voyage to the Pacific and Behring Strait, London, 1831, II, 159.

This writer says: "Respecting earthquakes at Rio de Janero, I could get no further information than that they are rare."

Francis de Castelnau.—Expédition dans les parties centrales de l'Amérique du Sud. Histoire du voyage. Paris, 1850. I, 202.

This author suggests that certain steep-sided ravines near Barbacena may be due to earthquakes, but he makes no mention of earthquakes having been reported.

In Vol. II at p. 83 he says that earthquakes are quite unknown in the central parts of Brazil.

When it is remembered that Brazil occupies an area almost as large

as that of the United States, one must regard the list here given as noteworthy, and probably impossible for any other portion of the globe.

It is quite probable that, with the natural increase of population and the increased facilities for communication, the frequency of earthquakes will appear to increase somewhat in the future, but such an increase will be apparent rather than real.

NOTES ON THE GEOLOGY OF CARRIZO MOUNTAIN AND VICINITY, SAN DIEGO COUNTY, CAL.[1]

WALTER C. MENDENHALL
U. S. Geological Survey

CONTENTS

INTRODUCTION

Through the courtesy of Dr. J. C. Merriam, of the University of California, and Dr. Stephen Bowers, of Los Angeles, small collections of fossil corals and mollusks from the vicinity of Carrizo Mountain, San Diego County, Cal., were sent to Dr. T. Wayland Vaughan and Dr. Ralph Arnold,[2] of the U.S. Geological Survey, during the autumn of 1903. The material in these collections proved to be of exceptional interest to the paleontologists, and in order that a larger amount might be obtained for study and more definite information secured about the geology of the region, Dr. Bowers and the writer visited the field during the latter part of January, 1904.

[1] Published by permission of the Director, U.S. Geological Survey.

[2] A brief preliminary statement of the conclusions reached by Drs. Vaughan and Arnold after an examination of these collections appears in *Science*, N.S., XIX, No. 482 (1904), 503. At that time the fauna was regarded as lower Miocene; later conclusions are to the effect that it is upper Miocene.

A light camping equipment was secured at Imperial and the drive made to Carrizo Mountain from this point. One day was spent at the Yuha Oil Well, studying the stratigraphy and collecting, then camp was established at Coyote Well on the Jacumba Springs Road. From this point Alverson Canyon and the southern slopes of Carrizo

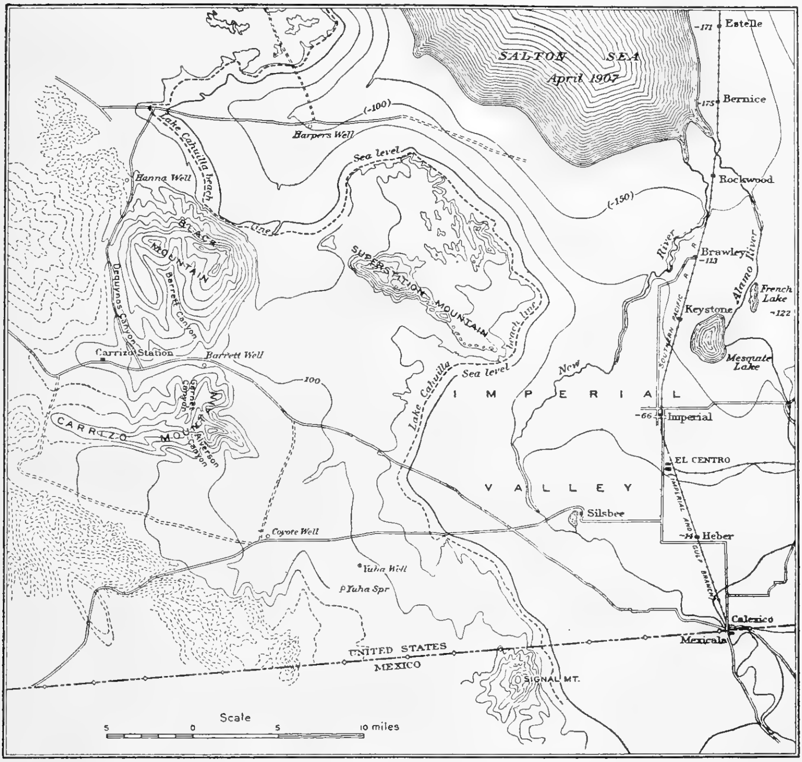


FIG. 1.—Sketch map of Carrizo Mountain and vicinity.

Mountain were accessible. Two days were utilized in work in this vicinity. Camp was then re-established about two miles below Carrizo Station, on the old stage road from Yuma to San Diego via Julian. From this point Garnet Canyon and the north slopes of Carrizo Mountain and Barrett Canyon and the south slopes of Black Mountain could be reached readily. After representative collections, amounting in all to about 1,500 pounds of material, had been made from the several fossil localities visited, the return trip to

Imperial was accomplished and the party disbanded. About ten days in all had been spent in the field.

Early Land Office maps, upon which neither roads nor relief are shown, were at that time the only official maps available, although since then, because of the rapid settlement of the Imperial Valley and the interest created in the region by the partial filling of the Saltòn Sink, the Geological Survey has issued a Reconnaissance Map which contains some details in the settled parts of the district but is very general in the vicinity of Carrizo and Black mountains, because these masses lie to the west of the area actually surveyed.

In 1900 and 1901 a number of oil companies were organized to prospect along the west side of the desert, between the base of the Santa Rosa Mountains and the Mexican line, and a number of engineers entered the district in the employ of these companies. Mr. I. A. Hubon and Mr. C. S. Alverson, of San Diego, were among these, and they collected data which, when assembled in a sketch map at Dr. Bowers' request, served to guide us in our field-work. From all these sources and from some sketches made by the writer the accompanying generalized map (Fig. 1) has been prepared. It does not pretend to topographic accuracy but indicates merely general geographic relations and general topographic facts without detail.

GEOGRAPHY

Black and Carrizo mountains, known also as Fish Creek and Coyote mountains, are eastern outliers of the Peninsula Range that separates the depression occupied in part by the Gulf of California from the Pacific Ocean. They are in southeastern California near the western edge of the Colorado Desert, and from fifteen to thirty miles north of the international boundary. East of them the Colorado Desert, much of it below sea-level, extends to the Colorado River, while to the west low ridges extend to the base of the main Peninsula Range.

The two masses are separated by the valley of Carrizo Creek. This stream rises in Mexico, flows north for several miles, through a high valley in the Peninsular Mountains, then descends to the Desert level through a precipitous canyon. Nearly all of that part of its channel that lies within the desert is dry except during rare

flood periods, when its waters join those of San Felipe Creek, north of Black Mountain, and eventually reach the Salton depression. At Carrizo Station, one of the relief stations of the old Butterfield stage line, a series of springs rise, and for one or two miles below this point flowing water is found in the creek bed, except during the hottest period of summer.

The desert floor at the eastern base of the peaks is generally from 100 to 200 feet above sea-level, but on the north side of Black Mountain the sea-level contour and the old beach of Lake Cahuilla,[1] 40 feet above sea-level, swing in against the mountain base. In the past the region has been rather difficult of access, because of its remoteness from settlements and its aridity. With the colonization of the Imperial Valley since 1900 and the building of the branch railroad from Old Beach to Calexico, however, this condition has been greatly modified. Now Carrizo Station or Coyote Well may be reached by one day's drive from Imperial or El Centro, and supplies are readily secured at many points in the valley. The old roads from the desert to San Diego, the one running north of Carrizo Mountain by way of Julian and the other south of the mountain by way of Jacumba and Campo, are still much used for direct communication between the Imperial Valley and the coast, although the Campo road below Mountain Springs is rough and after storms is nearly impassable.

EARLIER WORK

As yet there has been no detailed work done on the geological problems of the extreme southern part of California. Two important reconnaissances, however, have been carried out in that region and a number of other papers contain interesting notes.

Professor William P. Blake,[2] who accompanied one of the Pacific Railroad survey parties under Lieutenant Williamson through Southern California in 1853, wrote a comprehensive account of the

[1] *Nat. Geol. Mag.*, XVIII, No. 12, 830. In a note in this number of the *National Geographic Magazine*, Professor Blake proposes that the name Lake Cahuilla be applied to the vanished water body whose earlier existence is clearly proven by so many phenomena and whose history was first deciphered by Professor Blake himself. The name is most appropriate and the suggestion is most appropriately made by this distinguished worker.

[2] *Pacific Railroad Reports*, "Geology" (1856), V.

region which he visited and made a number of contributions of permanent value. He explored the Colorado desert, studied the effects of wind erosion in it, examined the old water-line which is so conspicuous a feature on the west side of the valley opposite Coachella and Walters, and worked out correctly both the origin of the lake whose former presence is attested to by it and the cause of this lake's disappearance.

Professor Blake made three trips along the valley of Carrizo Creek with the expedition, and brought out a few fossils which he collected from one of the flat, sandstone-capped hills on the north side of the valley. These were examined by Mr. T. A. Conrad, who pronounced the species new but probably of Miocene age.

Dr. Harold W. Fairbanks[1] visited Carrizo Mountain in the early nineties for the California State Mining Bureau, and while the exigencies of publication were such that a complete expression of his observations and conclusions was not possible, his paper is none the less very definite and satisfactory. He made hurried trips to the slopes of Black Mountain, which lies north of Carrizo Creek, and to Carrizo Mountain itself, and made collections from each locality. He described the fossils and the general geology of the district, and mentioned the corals which occur at the base of the sedimentary section.

Dr. Stephen Bowers,[2] of Los Angeles, visited the west side of the Colorado Desert in the summer of 1901, for the California State Mining Bureau. At that time there were a number of companies in the district drilling in the sedimentary rocks for oil. It was in connection with this oil excitement that Dr. Bowers' visit was made. He secured some fossils from the Carrizo and Black mountain localities which were submitted to Drs. Merriam, Vaughan, and Arnold. The interest aroused by these small collections led to the planning of the trip described here.

Other writers on the Colorado Desert have devoted themselves to general observations or to the description of particular features outside the Carrizo Mountain region. Among them may be mentioned:

[1] Fairbanks, H. W., *11th Rept., State Mineralogist of California*, 1893, 88, 90.

[2] Stephen Bowers, *Reconnaissance of the Colorado Desert Mining District*, California State Mining Bureau, 1901.

H. G. Hanks, "Mud Volcanoes and the Colorado Desert," *2d Ann. Report, State Mineralogist of California*, 1880–82, 227–40.

Chas. R. Orcutt, "The Colorado Desert," *10th Ann. Report, State Mineralogist of California*, 1890, 899–919.

Dr. Robt. E. C. Stearns, "The Fossil Freshwater Shells of the Colorado Desert, Their Distribution, Environment and Variation," *Proc. U.S. Nat. Museum*, XXIV (1902), 271–300.

GEOLOGY

GENERAL

Carrizo and Black mountains are islands of granitic and metamorphic rocks, which rise through encircling terranes of later sediments and volcanics. These later beds are Miocene and younger, and the unconformity which exists between them and the older rocks upon which they lie is profound. The time interval represented by this unconformity is not known because the age of the altered rocks below it is a matter of uncertainty. Fairbanks[1] expresses the opinion that they are Carboniferous or older, the opinion being based presumably upon their general resemblance to upper Paleozoic rocks in other parts of California and upon the aspect of some shells found in a float piece of siliceous limestone. Accepting this determination as the best possible in the present state of our knowledge, we must conclude that the Triassic, Jurassic, and Cretaceous systems are without depositional representatives in this region. Either the Carrizo and Black mountain areas were land masses subject to erosion during this interval or the evidence of such periods of deposition as intervened was later removed by erosional processes.

The Miocene seems to have been inaugurated by volcanic activity. On the southern slopes of both Carrizo and Black mountains are bedded tuffs, volcanic conglomerates, and less extensive masses of dark lavas of andesitic aspect. On Black Mountain there are distinct sandstones interbedded with these and directly upon them lie the Miocene coral reefs. In Alverson Canyon, which drains south from Carrizo Mountain, red vesicular lavas are succeeded by green and lavender sandstones and conglomerates, whose constituent materials are volcanic, and these in turn grade into conglomerates

[1] Fairbanks, H. W., *11th Rept., California State Mineralogist*, 1893, 88, 90.

with a diminishing proportion of volcanic pebbles. Above them are quartz conglomerates, tawny sandstones, and finally soft greenish-yellow clay shales.

An unconformity which is not especially conspicuous exists in the Miocene between the sandy shell-bearing beds, 100 feet or less in thickness, which immediately overlie the volcanics or the metamorphics, and the great mass of shales, greenish or yellowish at base, pink or pale red in general color-tone toward the top, which form the bad-land area (Fig. 2) that is especially well developed between

FIG. 2.—Lower Garnet Canyon and the adjacent bad lands cut in Miocene shales.

Black and Carrizo mountains. Finally, across the planed edges of these shale beds, a sheet of river cobbles, well rounded, has been distributed unconformably throughout the Carrizo Valley. They are probably Pleistocene, but are earlier than the silts, sands, and gravels, which represent the offshore and beach deposits of the lake which until recently has occupied the Colorado Desert. The latest erosion has left these old stream deposits stranded upon the remnants of the earlier valley floor at heights of from 100 to 200 feet above the present bed of Carrizo Creek.

DESCRIPTIVE

Basal series.—The core of Carrizo Mountain (Fig. 9) is a series of metamorphic rocks in which a blue or gray crystalline limestone is

predominant. Fairbanks reports that the limestones constitute the mass of the north face of the mountain. They are likewise present in great force on the divide between Alverson and Garnet canyons, where bands of graphitic schists are associated with them, but southwest along the first-named canyon, bands of dark biotite gneiss, which presumably represent early intrusives in the limestone, are abundant. Other fresh, dark, fine-grained intrusives, which may be related to the Miocene effusives, are found in narrow dikes.

FIG. 3.—Alverson Canyon and the west slope of Carrizo Mountain.

The bedding of the marmorized limestones and the imperfect foliation in the gneisses are approximately parallel to each other and to the longer axis of Carrizo Mountain. They usually are nearly vertical, the dips in either direction being 70 or 80 degrees.

The basement of Black Mountain was observed at only a few points where the fundamental rock juts out into Barrett Canyon. Here it is a granitic plutonic, with little or no evidence of the action of metamorphic forces. Fairbanks, who examined it at a point somewhat farther east, also speaks of the rock as a granite.

Effusives.—West of Alverson Canyon (Fig. 3), along the north slope of Carrizo Mountain, is a conspicuous exposure of ashy, laven-

der-colored tuff, which appears to lie directly upon the metamorphic rocks. Within the canyon itself and about midway of its length, an exposure of the variegated lava, andesitic in character, has at its base a thin bed of sandstone and conglomerate, while near the mouth of the canyon the sedimentary beds rest directly upon 50 feet of tuffaceous beds, which in turn overlie the older rocks.

No effusives were observed in the Garnet Canyon section on the north slope of Carrizo Mountain, but across Carrizo Creek, in the

FIG. 4.—View down Alverson Canyon from the south slope of Carrizo Mountain.

upper part of Barrett Canyon and especially in the ridge which separates Barrett Canyon from Deguynos Canyon, just west of it, is a heavy development of the lavas and tuffaceous beds.

Here, as on the south slope of Carrizo Mountain, there is some interbedding of sandstones with the flows, which evidently issued contemporaneously with the beginning of Miocene sedimentation. These interbedded sandstones are usually bright red or pink in hue, as though partly baked by the succeeding lava stream; hence they make conspicuous exposures among the more somber lavas. The uppermost lava flow, upon whose upper surface lies the coral reef (Fig. 6) at the head of Barrett Creek, is about 200 feet thick, and overlies a sandstone bed 20 to 50 feet thick. Below this more effusives extend below the bottom of the arroyo.

In this region the accumulated effusive materials are best displayed in maximum thickness in the ridge that has been mentioned between Barrett and Deguynos canyons. They must be more than 500 feet thick here. In Alverson Canyon their mass is much less.

Miocene conglomerates.—In the lower part of Alverson Canyon (Fig. 4) a heavy conglomerate bed 120 to 130 feet thick overlies a series of tuffaceous strata. This bed is composed of coarse material at the base but becomes finer toward the top. It is only moderately hard and along its upper margin is an abundantly fossiliferous horizon. Splendid coral heads are imbedded in these sandstones, and more delicate forms are found at the base of the superjacent sandy shales. These corals with the molluscan remains that accompany them, all of which await detailed examination and determination, prove the age of the inclosing rocks to be upper Miocene.

On the north slope of Carrizo Mountain, about the head of the eastermost arroyos which are tributary to Garnet Canyon, another series of fragments of a well-developed basal conglomerate are encountered. They extend well up the slopes of the older metamorphic rocks which form the axis of the mountain and dip away from it toward the north or northeast at the rate of 20 or 30 degrees. Being more resistant to weathering agencies than the soft overlying shales, these have been stripped from the sandstones at many points so that the old Miocene beach (Fig. 5), its sands indurated and its teeming life preserved only in fossil form, but yet exhibiting much the aspect and much the same relations which existed at the time of its deposition, is revealed for the modern student's inspection. These basal sands are not always found where their horizon is exposed. In many places the fine clays that were spread out over the sandstones were deposited directly upon the metamorphic rocks that form the core of the mountain and must at one time have formed the bottom and shores of the Miocene sea. The simplest interpretation of this relation is to suppose that before that change of conditions was complete which substituted muddy brackish water with oyster colonies for clear sea water and marine life, the sands of the earlier beach had been swept away, so that there is unconformity, without discordance, or at least without marked discordance in dips, and without a great time interval between the deposition of the sands and

FIG. 5.—Sandstones representing the Miocene beach on the north face of Carrizo Mountain.

the deposition of the muds. The other hypothesis, namely, that these beach sands and the muds were deposited contemporaneously, because of differing local conditions, is made difficult to apply because the two physically different terranes overlie the basement rocks at very closely adjacent points, with no obvious explanation as to why such different conditions should have prevailed so near together.

The heavy sandstones occur at a number of places along the north slope of Carrizo Mountain, east of the head of Garnet Canyon. Many arroyos are incised in them, the stream channel in some cases being a mere notch but a few feet wide and a hundred or more deep. Fossils, however, have not been reported in numbers except at the head of Garnet Canyon.

At the head of Barrett Canyon, which drains south from Black Mountain, the same general relations prevail that have been described in the area a dozen miles to the south on the slopes of Carrizo Mountain. But the fragments of the basal beds of the Miocene are even more widely scattered, and the sandstones and conglomerates are not so fully developed.

About 4½ miles above the mouth and one-half mile above the forks of the Arroyo, the basal beds of the Miocene flank the older rocks and extend across the valley from the west fork to the east fork. Dips here are 20 to 40 degrees to the south, i.e., away from the mountain. The beds are not so thick as on Carrizo Mountain but are succeeded, as is the case there, by soft yellow shales.

About a mile above this point, in a little cove at the head of a small western tributary of Barrett Creek, other outcrops of basal sandstone and conglomerate, not more than 10 feet thick, occur with the underlying igneous rocks all about them. Near this outcrop is a fossil coral reef lying directly upon the lavas and isolated from all the other sedimentaries (Fig. 6). A half-mile farther north a sheet of sandstone, folded into a basin and thus somewhat protected from erosion, still exists. Doubtless many other similar fragmental exposures would be revealed by more extended search.

Miocene shales.—Flanking Carrizo Mountain on nearly all sides and extending on the southeast practically to Signal Mountain, on the international boundary, are continuous exposures of the beds which overlie the basal conglomerate. They are well developed also

on the southwest slopes of Black Mountain. The middle drainage basin of Carrizo Creek is a bewildering bad-land area (Fig. 7) formed by the sharp dissection of these soft clays. For many hundreds of feet above the conglomerate, the shale beds contain only occasional strata of thin brown nodular sandstone, hence they form smooth clay hills. They are entirely destitute of vegetation because of the aridity of the region, so the area in which they are found is desolate in the extreme. Fresh outcrops of the shales are to be seen only

FIG. 6.—Fossil coral reef near the head of Barrett Creek.

along the flood channels where there has been recent cutting. Ordinarily each shale hill is mantled by several feet of residual material, dust much the greater part of the time, soft adhesive mud during the occasional desert rains. This mantle is the result of the weathering of the soft shales. Exposed to the air, they disintegrate completely and rapidly. This action is probably aided by the efflorescence of certain of the alkali minerals which are abundant in the shales. Wherever a thin sandstone is interstratified with them, it partially preserves them from the rapid disintegration which ordinarily affects them and so usually caps a hill which stands above the general level of the unprotected shale. Such low structural monadnocks are numerous in the neighborhood of Barrett's Well (Fig. 2).

Farther to the east and south, as in the vicinity of the Yuha Oil Well, at horizons which are presumably higher than those in the Carrizo Valley, although the conditions governing our brief reconnaissance were such that it was not possible to determine the relations with any certainty, the sandstone beds are more abundant. Many of them here weather in curious nodular forms of great variety. Such forms have been well described by Professor Blake.[1]

FIG. 7.—Erosion in the Miocene shales of the Carrizo Valley.

The Carrizo Valley is synclinal, the shales rising gently northward and southward from the axis of the valley toward the bases of Black and Carrizo mountains. Near the borders dips of 5° to 20° were measured, while in the center of the valley the beds are nearly horizontal or exhibit irregular attitudes. Faults of small displacement were noticed near the head of Garnet Canyon, others north of Carrizo Creek have been described and figured by Blake, and Fairbanks believes that the abrupt eastern face of Black Mountain overlooking the desert is a fault scarp.

In the vicinity of Yuha Oil Well more pronounced structures

[1] "Explorations and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean" (War Dept., 1857), *Geological Report* by Wm. P. Blake, p. 102.

exist, at least one district anticline with a northeast-southwest axis having been observed half a mile south of the well.

No attempt was made to measure the thickness of these beds, but the buff clays in the middle Carrizo Valley must aggregate 1,000 feet or more, and the beds with a distinctly reddish tone, which are more prominent above Carrizo Station and southeast of Carrizo Mountain, overlie them. The oil well at Yuma starts in sandy strata which appear to be stratigraphically higher than the reddish clays, and at

FIG. 8.—Old water-line marking the shore of Lake Cahuilla west of Coachella.

the time of our work in January, 1904, had penetrated over 700 feet of alternating sandstone, shale, gypsum, and shell beds.[1] The thickness of the basal conglomerate on either side of Carrizo Mountain is about 200 feet, as indicated in the generalized sections of Garnet Canyon (Fig. 10).

Superficial deposits.—The shale bluffs along Carrizo Creek, 50 to 100 feet high, are capped in many cases by a deposit of river cobbles three to ten feet in thickness. These cobbles are distributed over practically all of the lower shale hills within the valley whose tops are broad enough to retain the alluvium. Dissection has been so

[1] This well was afterward deepened to about 1,200 feet, but the full record is not available.

complete that the majority of these summits are reduced to mere points and lines. In these cases the arroyos and the slopes below the summits are often cumbered with the river wash which has slumped down as the hills have been reduced, but has not yet been removed. This material represents a variety of metamorphic and igneous rocks probably derived from the Peninsula Range and its outliers. Its deposition dates back to an earlier erosional cycle, when the present tops of the bad-land hills formed the bottom of the valley of the ancestor of Carrizo Creek.

Within Carrizo Valley proper and in the lowland south of Carrizo Mountain, there is the usual desert accumulation of washed material

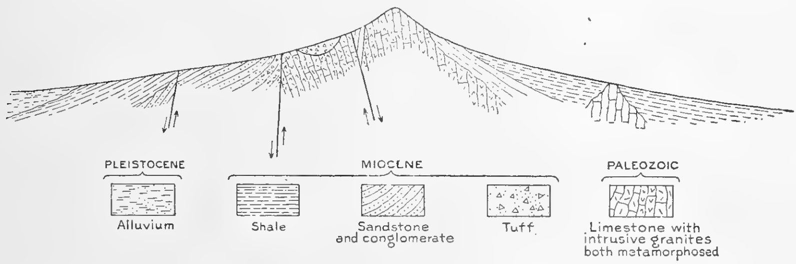


FIG. 9.—Diagrammatic section across Carrizo Mountain by way of Alverson and Garnet Canyons.

grading upward toward the mouth of each canyon into alluvial cones. West of Carrizo Station and at other favorable points in adjacent parts of the desert, there are many sand dunes, but these reach a greater development in the more open desert to the north and east.

Passing eastward beyond the valley of Carrizo Creek toward Imperial, the road at first traverses areas of well-reduced shales and sandstones, and then reaches a broad zone of beach gravels full of well-preserved shells of modern types.[1] This zone represents the beach line of the extinct lake that once occupied the Colorado Desert. The beach is not as distinct as a physical feature here as at many points farther to the north (Fig. 8) because the shore line

[1] Robt. E. C. Stearns, Ph.D. "The Fossil Freshwater Shells of the Colorado Desert, Their Distribution, Environment, and Variation," *Proc. U.S. Nat. Museum*, XXIV, 271–99.

itself was shelving and indefinite, but its general position is well marked by the molluscan remains.

Beyond and below the gravel zone is one of sand, and still farther east beyond this is the silt-covered bottom of the old lake Cahuilla. The deposits here are impalpably fine, laminated clays which, when stirred, as in a much-traveled road, become a tawny flour and when moistened are transformed into a smooth, adhesive mud.

RÉSUMÉ OF GEOLOGIC HISTORY

The story of the development of this part of the country cannot be read with any approach to accuracy as yet for any period beyond the Miocene. The rocks which represent earlier time are marmorized limestones, schists, and gneisses as to whose age there is much doubt. The slight existing evidence points toward the Carboniferous as the period during which the limestones were deposited here. Whatever their age, their condition now indicates that their history previous to the Miocene was one involving deep burial and intense earth strain. They were upturned, intruded, and crystallized, uplifted and eroded into a mountainous topography, and at the beginning of the late Miocene formed islands in a sea teeming with life. Volcanic forces were active at this time and the flanks of the old land mass are partly buried under the effusive material which issued then, and the muds and the littoral whose fragments were supplied from volcanic sources are conspicuous at many points. But as the period advanced, vulcanism ceased and the present Carrizo and Black mountains were surrounded and perhaps for a part of the time were submerged beneath a clear sea in which the myriad forms of the life of the period swarmed. Still later in the Miocene the character of the sea changed. Instead of clear, salt water, some re-alignment of forces caused great quantities of muddy brackish water to spread about the old islands. Oysters of many forms, some of them of great size, some very tiny indeed, flourished. The heavy silts of these muddy waters accumulated to great depths as the land subsided. Finally the waters withdrew, presumably because of re-elevation, and the region was land again as it had been before, and the shells of many of the creatures which had lived in the clear and then in the muddy waters were preserved in the accumulated

sediments. As the sea withdrew, the destructive forces of weathering and the erosive forces of wind and running water became active. The clays which had accumulated were now dry and were cut away again by these forces. The process was not long continued and the plain was not completed, those clay areas which were capped by protecting sandstones remaining as monadnocks above the wide valley floor. This valley, occupied by an earlier vigorous ancestor of Carrizo Creek, was strewn with rounded river cobbles brought from the higher mountains to the west. South and east of Carrizo Mountain large areas seem to have been reduced at this period well toward the condition of a peneplain. This plain lies perhaps two hundred feet above the later Pleistocene lake-level with which it seems to have no connection. It is regarded as an earlier independent feature, perhaps Pliocene in age.

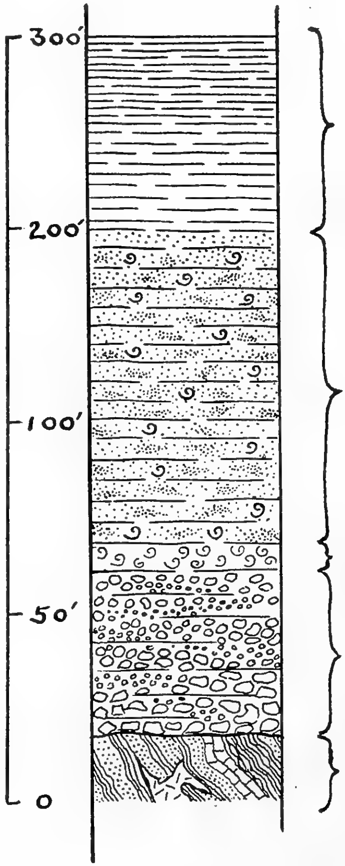


FIG. 10.—Columnar section of rocks exposed in Garnet Canyon.

After the formation of this partially planed surface, over the soft rocks of Carrizo Valley, some change either in the relations of land and sea, or of climatic conditions, enabled the streams to dissect it again. The result of this dissection, which may well have been contemporaneous with the last occupancy of the Colorado Desert by the Gulf of California, is seen in the Carrizo Creek bad lands of today.

The last important element in the development of the geography of this part of the desert was the formation and the disappearance of the desert lake. So late is it, that the calcium carbonate incrustations which it left on its western shore (Fig. 8) show but little

effect of erosive or solvent action since the waters left them, and the sandy beach, molded by the waves of the lake upon the alluvial fans which formed a large part of its shores, is still well enough preserved to be readily traced. Only the most modern gullies have cut it away. At one point a low sea cliff notched by the waves in steep alluvial-fan material still stands, as perfectly preserved as though the waters had just withdrawn.

CONCLUSION

In conclusion it is to be said that but the barest outlines of the history of this fascinating region are yet known. Its rocks contain a rich upper Miocene fauna, probably in large part new, and its exposures and structures are so clear that its geology will be an open book to the fortunate student to whom falls the pleasant task of deciphering it in detail.

FOSSIL LOCALITIES[1]

Shells are very abundant in the vicinity of Yuha Oil Well, but the variety is not as great here as at other localities where collections were made. A few hundred yards west of the well is an outcrop of an oyster bed which makes a conspicuous shell mound and other similar outcrops exist in the vicinity.

The horizon is the highest at which collections were made. It is probably a few thousand feet above the Carrizo and Black mountain horizons. Collections Nos. 160 and 161 were made near Yuha Well, and No. 162 was made about one and one-half miles southeast, but the horizons are not believed to be far apart.

Collection No. 165 is from a point about two miles east of the base of Carrizo Mountain. Shells are abundant here but species are limited, as is true of the vicinity of Yuha Well. These shells are probably stratigraphically lower than collections Nos. 160–62 but are higher than the others except possibly No. 168.

Collection No. 168 was made on the county road, near Barrett's Oil Well. The locality is nearly midway between Carrizo and Black mountains and must be from substantially the same horizon as Blake's original collection. It is also near the horizon of No. 165, but may be slightly lower.

No. 163 is from a small arroyo just east of Alverson Canyon, on the south side of Carrizo Mountain. The shells were taken from the yellow clays which immediately overlie the basal conglomerate. These clays contain a rich fauna which is not by any means fully represented in the collection. Stratigraphically these beds belong above the three collections yet to be mentioned. The length of the time interval between the two horizons depends upon the extent of the

[1] These descriptive notes are introduced for the use of the paleontologists who may eventually study the collections now in the U.S. National Museum.

unconformity between the conglomerates and the clays. It is probable that this interval is slight, but there are no data at hand for estimating it.

Nos. 164 and 166 are from Alverson Canyon and the head of Garnet Canyon on the south and north slopes respectively of Carrizo Mountain. The horizons are identical, being in each case the sandstones which form the upper part of the arenaceous series at the base of the Miocene. These are the most conspicuous fossil localities in the region. The shells or their casts have weathered out and strew the slopes in great profusion. Corals, echinoids, ostrea, pectens, strombus, and malea are everywhere. The matrix, however, is coarse, and only large and robust types are well preserved. The locality has been noted by prospectors generally, because the occurrences are so conspicuous.

No. 167. This collection consists of corals almost entirely. The fossil reef is near the head of Barrett Canyon and lies directly upon the igneous rocks which served as a basement for Miocene sedimentation at this point Whatever later beds may have originally covered it have been stripped away, so that the old reef is now isolated. There can be little doubt; however, that its position is at the base of the Miocene series and substantially equivalent to that of Nos. 164 and 166.

AMPHIBIAN FOOTPRINTS FROM THE MISSISSIPPIAN OF VIRGINIA

E. B. BRANSON
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In the summer of 1908 a geological field party from Oberlin College collected a series of amphibian footprints from the Mississippian of Giles County, Virginia. The horizon of the prints was near the bottom of the Hinton formation, but as the line of demarkation between the Hinton and the underlying Bluefield formation is not sharply drawn it was impossible to determine the exact distance above that contact. The Bluefield in this region is about 1,300 feet thick according to Campbell, and the Hinton about the same thickness. The horizon of the tracks is about 1,300 feet above the Greenbrier limestone which lies just below the Bluefield, and 1,300 or 1,400 feet below the equivalent of the Pottsville. According to Stevenson the Bluefield and Hinton are to be correlated with the upper part of the Mauch Chunk of Pennsylvania, and it was from the Mauch Chunk of Pennsylvania 700 feet below the Pottsville conglomerate that *Sauropus primevus* Lea was collected.

The Hinton shales, like the Mauch Chunk, seem to have been subaerial in origin and are made up for the most part of variegated shales interbedded with thin layers of argillaceous, fine-grained sandstone. The footprints occur in fine-grained sandstone, and remains of land plants are not uncommon in the same beds. No marine fossils were noted by the writer in his examination of the Hinton excepting in one horizon, and that probably represented a brief transgression of the sea over delta flats. The fossils were rare and belong to only four or five species.

Twenty-two footprints made by one animal walking in a straight course were collected in a slab. They give the impression of having been made by a bipedal animal for part of the distance, but after the fourth print of the right foot impressions of the forefeet appear. The distance from tip of toe to tip of toe in the first prints is about

21 cm., but with the appearance of the prints of the forefeet the distance apart is 165 mm., 40 mm., 85 mm., 70 mm., 80 mm., 40 mm., 150 mm., and then back to 20 and 21 cm., with no more prints of the forefeet. Where only the prints of the hindfeet appear the impressions are deeper.

The hindfeet were 60 mm. in length, and 20 to 25 mm. in breadth. They had five digits, the middle digit being the longest and the two inside of it being only slightly shorter and lying close together. Their outer ends were slender and flexible and usually curved inward toward the middle toe. The two outer digits formed wide angles with the middle one and were shorter than the inner ones. The second toe was webbed to within 8 mm. of the tip, the third toe to within 23 mm. of the tip. The impression of the web is well preserved in only one impression of the hindfoot. The heel was narrow, 10 to 12 mm. in length, and not well enough distinguished in the prints to determine its exact shape.

FIG. 1.—*Dromopus aduncus* $\frac{1}{5}$ natural size.

The forefeet were 45 mm. in length and had four digits. The three inner digits were subequal in length, the two inner being more flexible and incurved near the ends. The outer digit is two-thirds as long as the second. The webbing extends about half the length of the digits. The heel impression is broader than that of the hindfoot.

The distance between the inner parts of the impressions of the right

and left feet is 35 mm. and between the outer parts 90 mm. No impression of a tail is present.

The photograph reproduced in Fig. 1 is of that part of the slab showing only impressions of the hindfeet, but opposite the posterior impression a fragment from farther forward containing a track of the left forefoot is inserted. All of the feet have the heel impression shown rather indistinctly. The photograph shows the impressions of the hindfeet just behind the place where impressions of the forefeet appear.

It hardly seems worth while to attempt to classify the specimen under discussion but such an attempt may lead to a better understanding of its relationships. Using Matthew's classification it should be referred to the genus *Dromopus,* and the specific name *aduncus* is suggested, referring to the inward bending of the outer ends of the inner toes.

Amphibian footprints have been recorded from the Mississippian of America as follows:

Paleosauropus primevus Lea from the Mauch Chunk near Pottsville, Pennsylvania, about 700 feet from the top of the formation (*Proceedings of the American Philosophical Society,* IV [1849], 91–94, one figure).

Three unnamed varieties from about 2,200 feet from the top of the Mauch Chunk of Pennsylvania (Rogers, *Geology of Pennsylvania,* Part II [1856], 831).

Hylopus hardingi Dawson and *Hylopus logani* Dawson from the Subcarboniferous of Nova Scotia (*Transactions of the Royal Society of Canada,* XII, sec. iv [1894], 78).

One form from "not far from the horizon of Sauropus primaevus" in Pennsylvania (J. Barrell, *Bulletin of the Geological Society of America,* XVIII [1907], 460).

ROCK GLACIERS IN ALASKA[1]

STEPHEN R. CAPPS, JR.

It is a generally admitted fact among observers of present-day geologic processes in high latitudes, but one upon which too little emphasis has been placed, that processes of weathering and removal of rock waste in sub-arctic regions are different from the controlling processes of degradation in more temperate regions. Among the better-known special agents of erosion active at high altitudes in temperate regions as well as in lower altitudes in sub-arctic regions, is the action of glacial ice. Of the processes not so well understood or appreciated is that of the flow of soils, or "solifluction," described for Bear Island of the North Atlantic Ocean by J. G. Andersson.[2] Mr. Andersson considers "solifluction" to be an important agent in the peneplanation of areas in high latitudes, and the process is without question a most important one in many parts of Alaska. Other processes which, according to Daly,[3] may be effective in producing an accordance of summits in mountainous regions, accordances which are generally referred to as indicating dissected peneplains, are frost action, glaciation, and wind erosion, all of which are relatively more effective above the vegetation line than below it. The accordance of summits, it is suggested, is produced by the selective action of these agents in attacking most vigorously the higher peaks. Even the ordinary processes of stream erosion are different from those of temperate climates, for the streams are frozen for about seven months a year, and during the open months their action upon the detritus is greatly influenced by the permanently frozen character of the soil, and by ground-ice.

The special agents of degradation with which I wish to deal at

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] J. G. Andersson, "Solifluction, a Component of Subaerial Denudation," *Jour. Geol.*, XIV (1906), 91–112.

[3] Reginald A. Daly, "Summit Levels among Alpine Mountains," *Jour. Geol.*, XIII, No. 2 (1905), 105.

present, however, I have called *rock glaciers*. These rock glaciers occur in unusual numbers and attain exceptionally perfect development on the Nizina Special Quadrangle, where I had an opportunity to study them in the summer of 1909 while working on the geology of the region in a U.S. Geological Survey party in charge of Mr. F. H. Moffitt. The center of the area lies at longitude 143° 40′ W., latitude 61° 20′ N. On the sheet there are more than 30 of these rock glaciers and the valleys which they occupy are in every case cirques excavated at the time of the maximum glaciation of these mountains. The valleys are still on the very border line of glacial conditions, and in fact many of them still have small glaciers at their heads. The great Kennicott Glacier, in the main Kennicott Valley, occupies the bottom of the valley into which many of the rock glaciers discharge. Fig. 1 is a topographic map of a portion of the area.

In material the rock glaciers are composed of angular talus, such as goes to make up the ordinary talus slope, the kind of rock being that of the cirque walls above—porphyry, limestone, greenstone, or shale. In most cases the fragmented rock extends all the way to the head of the cirque, with no ice visible and with little or no snow on the surface. In several instances, however, the rock glaciers grade into true glaciers at their upper ends, without perceptible break. There is, therefore, a complete gradation between the two.

They vary greatly in size, but are usually many times longer than wide, occupying, as they do, the bottoms of cirque-like valleys. Some have wide, fan-shaped heads, and narrow down to a tongue below. Others are narrow above, and deploy into spatulate lobes below (Fig. 1, No. 1). Still others are formed by the junction in a valley of rock glaciers from two or more tributary valleys (Fig. 1, No. 5), but the greater number are narrow bodies of nearly uniform width, from one-tenth to one-fourth of a mile wide and from one-half to two and one-half miles long. The surface slopes vary in different cases from 9° to 18° for the whole course of the rock glacier. As topographic features they are well brought out on Mr. Witherspoon's topographic map of the area, a portion of which is shown in Fig. 1. The individual rock fragments are for the most part small, but attain, in exceptional cases, a diameter of several feet. Six inches would perhaps be about the average diameter in those rock glaciers which are com-

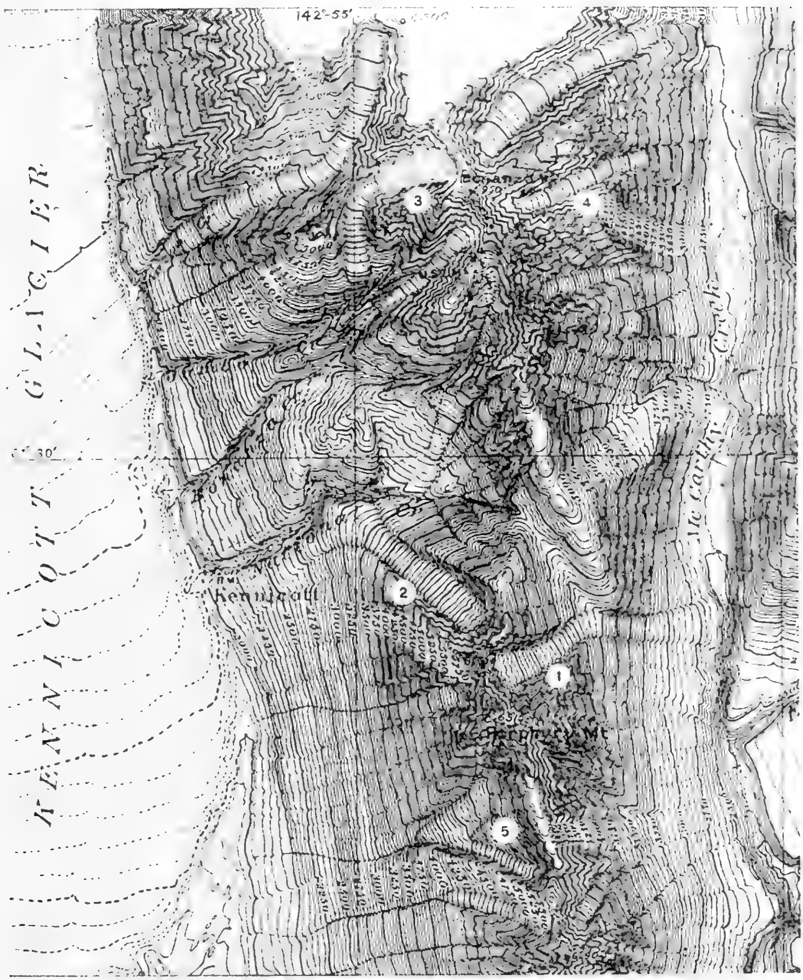

FIG. 1.—Topographic map of about 33 square miles of the Nizina Special Map. Eleven rock glaciers occur within this area. The numbers refer to descriptions in the text. Topography by D. C. Witherspoon.

posed largely of the porphyry, while in the greenstones and limestones the average size of the fragments is larger, and in the shales smaller than this.

The rock glaciers in form and position resemble true glaciers in noticeable ways. They head in cirques and extend from these down the valley, in cross-section being highest above the valley axis and sloping down sharply on the sides. Some were seen to have distinct lateral moraine-like ridges, and all show a more or less well-marked longitudinal ridging.

The surface markings of these rock glaciers are characteristic and striking. In the upper portions there are often many parallel longitudinal ridges, with depressions a few feet deep on either side. The sides below the cirques are usually separated from the rock valley walls by a sharp trough. Toward the lower ends the longitudinal ridges often become less prominent and give place to concentric wrinkles paralleling the lower end of the rock glacier. At the lower edges, the slope often steepens to the angle of rest for the material. The whole appearance gives one a decided impression of movement, as though the material had moved forward from the cirques in somewhat the manner of a glacier, the longitudinal lines simulating moraine lines.

The marked resemblance of these forms to glaciers led to the suspicion that ice was in some way responsible for their movement. To determine whether or not this was the case a number of the rock glaciers, seven or eight in all, were dug into, and in every instance clear ice was found; not massive ice, however, but interstitial ice, filling the cavities between the angular fragments and forming, with the rock, a breccia with the ice as a matrix. The depth below the surface at which ice was found varied according to the elevation of the rock glacier and to the portion of it examined. Toward their lower ends the ice lay too deep to be found by any shallow diggings which we had time to make. Farther up, toward the cirques in which they headed, the ice could usually be found within a foot or two of the surface, if a depression was dug into. It was often easy to get a drink of water by digging at a point where the sound of running water could be heard, and in these places clear water was found running along shallow courses among the ice-filled talus.

There is a sharp distinction between these rock glaciers and true glaciers, although in some cases it may be difficult to draw the line between the two. For the formation and existence of a true glacier it is necessary to have an annual surplus of snowfall over melt, or, in other words, to have névé fields to supply ice to the glaciers. The greater number of rock glaciers, on the other hand, are found in cirques where all, or practically all, of the winter's snowfall disappears during the summer. In true glaciers, no matter how heavily moraine covered they may be, there is always a tendency to crevass where the ice rounds a bend or passes over an inequality of the bed, and pits and irregularities of the surface are common at the lower ends where the underlying ice melts out and allows the moraines to cave in. In the rock glaciers no certain crevasses or cave-in pits were seen, and these are not to be expected if the rock glaciers are composed, as they seem to be, of talus with ice only in the interstices, for the talus itself is self-supporting without the ice, and the melting of the ice would have little effect on the surface appearance of the flow. This of course is true only of those rock glaciers which show no glacial ice at their upper ends. Of those which head in true glaciers (Fig. 1, No. 3) the upper ends would be profoundly altered if the ice should disappear, but the lower ends would probably present about the same appearance as they do now. The rock glaciers also differ from true glaciers in that, although they may advance spasmodically, or at varying rates, they never retreat, for their form remains intact even if the ice melts out and movement ceases.

The conditions necessary for the formation of one of these rock glaciers are considered to be as follows:

With the wane of the last great epoch of glaciation, the ice in many small valleys which contained glaciers was retreating, and as its area contracted in the cirques, the head walls and sides, steepened by glacial undercutting and by *Bergschrund* sapping, were exposed to the rapid weathering characteristic of bare rock surfaces in the high altitudes of this region. In the more favorably situated of these cirques the rock waste streamed down the valley sides and heads upon the glacier below and was gradually carried down by the ice and ultimately concentrated at its lower edge. Here, in the usual order of events, it would have been piled up as terminal moraine, but differ-

ing in character from the common forms of terminal moraine material in its angular, talus-like appearance and the absence of finer muds and rock flour which form such a large part of the moraines of active glaciers. Here the small, fast-dying glaciers were eroding but little, and were almost overwhelmed by the débris supplied them from above. Into the detritus at the lower edge of the glacier the waters from the melting ice and snow and from rains sank and froze, and gradually filled the interstices with ice up to a point below the surface where melting equaled the freezing. In these ice-cemented masses an incipient glacial movement was started by the well-known process of melting and refreezing of the waters, with their consequent expansion. As the climate became still milder, in many of the cirques the winter's snows all melted away during the summer, so that conditions for ordinary glacial activity no longer existed, but the bodies of talus which reached the cirque floor became filled with interstitial ice, and the movement of the mass in a glacier-like way has continued, although no doubt all true glacial ice has disappeared from many of these rock glaciers. It is certain that much snow is still carried down onto the surface of the rock glaciers in slides of ice and rock, and considerable quantities of it may be covered by débris and incorporated into the rock glaciers, but this snow probably forms only a small part of the total mass of the flow.

The above succession of events seems to be well established in this region, for there are now all stages varying from apparently active glaciers with short rock glaciers below, to rock glaciers in which no glacier ice is seen, in valleys where all snows disappear during the summer, yet in these the slow movement seems still to be in operation, the rate of movement in each rock glacier controlled by the supply of talus from above and by the shape and grade of the floor over which it moves. The rock glaciers are, therefore, the true successors of real glaciers.

The particularly perfect development of these features in the area of the Nizina Special Map is due to the rugged character of the mountains, with cirques having steep heads and sides; to the exceptionally favorable conditions for rapid rock weathering and talus accumulation; and to climatic conditions peculiar to areas on the border line of glacial activity.

FIG. 2.—Rock glacier on McCarthy Creek (Fig. 1, No. 1). Especial attention is called to the absence of perennial snows at its head; to the longitudinal direction of the surface linings in the upper portion, and to their concentric arrangement in the broad lower portion. Photo by F. H. Moffitt.

The rock glacier which was studied in most detail lies on the west side of McCarthy Creek, east of Kennicott (Fig. 1, No. 1). Although neither so long nor so large in area as others within the limits of the Nizina Special Map, it presents in a typical way many of the notable characteristics of all of the flows (Fig. 2). This rock glacier heads in a glacial cirque in a mountain composed largely of porphyry but

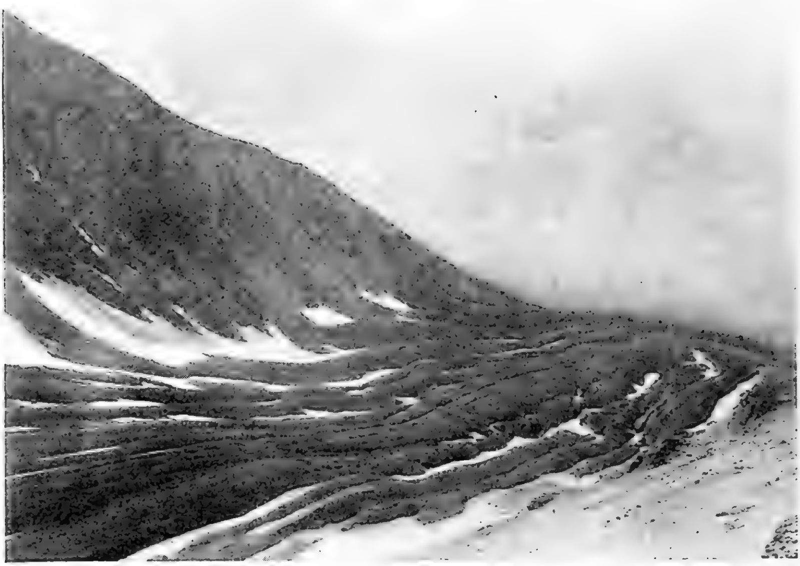

FIG. 3.—The upper portion of a rock glacier (Fig. 1, No. 2), showing the character of the longitudinal ridges, and their relations to the talus slopes in which they head.

having many inclosed masses of black Jurassic shale, the mountains at the cirque head reaching a maximum height of 6,315 feet. The rock glacier occupies the cirque floor below an elevation of 5,250 feet. Above this talus slopes extend upward for about 200 feet, the remainder of the cirque walls being bare, ragged cliffs. The porphyry is much fractured and the formation of talus unusually rapid. The valley head lies below the elevation necessary for the maintenance of true glaciers, and the winter's snows disappear completely during the summer. On July 4, the time visited, but little snow remained.

The rock glacier heads in the talus cones which have formed at the base of the steep rock cliffs. These cones have nowhere grown to large size, the materials evidently having moved on down valley as parts of a rock glacier as fast as they were supplied from above. From the base of the more vigorous talus cones smooth, ridgelike lines extend on down the rock glacier, seeming to show that the forward

FIG. 4.—Profile of rock glacier on McCarthy Creek (Fig. 1, No. 1). The surface scope of the rock glacier conforms in a noticeable way with the glacial U-shape of the McCarthy Creek valley.

movement has been uniform and continuous. This is especially well shown for the flow on the opposite side ot the ridge (Fig. 1, No. 2), in Fig. 3. The longitudinal ridges mark the surface for the upper three-fourths of the total length of the flow. The cirque basin is a hanging valley extending down to an elevation of about 4,000 feet, below which it joins the broad V-shaped valley of the McCarthy Creek. As it passes over the lip of this hanging cirque the rock glacier cascades steeply down the valley side (Fig. 4), and upon reaching the gentler slope below, being no longer confined by restricting valley

walls, it spreads out in a great lobe along the valley bottom. In this lower lobe the longitudinal surface markings disappear and give place to a set of concentric ridges or wrinkles, shown in Fig. 2, and in greater detail in Fig. 5. The origin of these wrinkles is not clear, but they strongly suggest rings of growth, and may represent the amount of annual movement of the rock glacier.

FIG. 5.—Concentric ridges on lower portion of rock glacier in McCarthy Creek valley (Fig. 1, No. 1).

At its foot the flow has pushed across the valley bottom almost to the base of the east valley wall. McCarthy Creek has been forced to the eastward, and occupies a narrow channel between the foot of the rock glacier and the rock valley wall (Fig. 6). The foot of the rock glacier is being cut into by the stream, and in places shows a face 75 to 100 feet high in which the slope is about 35 degrees, or the angle of rest for this material. The stream has been able only to keep its channel open along the foot of the rock glacier, and it seems probable that the flow is moving forward as fast as the stream can cut it back.

I have been able to find in the literature scant reference to features of this kind. In the Falkland Islands there are so-called "stone rivers," described by Thomson,[1] Andersson,[2] and others, which seem to correspond closely to those in the area here described, but which occur on much lower slopes. Andersson, in an article on "Solifluction," or soil flow, thinks that these Falkland "stone rivers," which now

FIG. 6.—Lower end of rock glacier on McCarthy Creek (Fig. 1, No. 1). The material at the edge lies at an angle of 35°. The stream has been able to keep open only a narrow channel at the base of the rock glacier.

are composed of angular blocks, were formerly filled with fine mud and that the blocks of rock, buoyed up by the mud, slowly flowed down the valleys. He conceives that the fine material has since been removed by running water. There is now no movement of these "stone rivers."

The rock glaciers do not fall under the term "solifluction," as used by Andersson, for he describes a movement of rock débris com-

[1] Thomson, *The Atlantic*, 245. [2] J. G. Andersson, *op. cit.*

posed of angular fragments mingled with a matrix of mud, which moves as a viscous fluid. The material of the rock glaciers is for the most part coarse and angular, and instead of a semi-liquid filling of mud, the interstitial openings are filled with solid ice, except in the surface portions, where there is no filling at all.

There is also an opportunity for interesting comparisons with the rock slides of the San Juan Mountains of Colorado, so well described by Cross and Howe[1] in the Silverton Folio and by Howe[2] in a recent publication. At first glance there seems to be a great similarity between the rock streams of the Colorado Mountains and the rock glaciers of the area under discussion. Both are composed of angular talus from high mountains, and show some striking similarities in appearance and in surface configuration. I am convinced, however, that the rock glaciers of the Nizina region are not formed in the way in which Mr. Howe[3] explains his rock streams, by a flow down the slopes "with a sudden violent rush that ended as quickly as it started." No opportunity has so far been had to make a series of observations extending over a considerable period of time to prove conclusively that these rock glaciers are in motion, or to determine the rate of movement. There are a number of facts, however, which seem to lead inevitably to this conclusion.

In the Silverton Folio, published in 1903, Cross and Howe state: "The larger rock streams, however, must owe their origin to glaciers; no other agencies could transport such vast quantities of rock waste so far from their sources." Later, Howe has published his opinion that the rock streams of the San Juan Mountains are really landslides, which occurred in a sudden violent rush of material. In this opinion Cross now agrees with him.

In his description of the great Elm landslide, Heim[4] has pointed out that sudden landslides may have a form remarkably similar to that which is developed by slow movement, and it is well to keep this

[1] Whitman Cross and Ernest Howe, *U.S. Geol. Sur. Folio*, No. 120, Silverton.

[2] Ernest Howe, "Landslides in the San Juan Mts., Colo.," professional paper, *U.S. Geol. Sur.*, 67, 1909.

[3] *Ibid.*, p. 54.

[4] Albert Heim, "Der Bergsturz von Elm," *Zeitschr. Deutsch. Geol. Gesell.*, 1882, 98.

fact in mind. McConnell and Brock,[1] on the other hand, in their report on the Frank landslide, fail to report any systematic ridgings like those at Elm, or in the rock streams of the San Juan Mountains.[2]

Perhaps the most indicative facts which lead us to conclude that the rock glaciers of the Nizina region are now in motion, moving in some such way as a glacier, are:

FIG. 7.—The upper end of a rock glacier, showing the cirque-like character of the valley head, and the origin of the longitudinal ridges in the talus slopes of the head walls.

1. The remarkable resemblance in position and form to present live glaciers in the immediate vicinity.

2. The direct connection and perfect gradation between present glaciers above and long rock glaciers below.

3. The presence of interstitial ice at no great depth below the surface in all of the rock glaciers which were dug into.

[1] R. G. McConnell and R. W. Brock, "Report on the Great Landslide at Frank, Alta., 1903," *Ann. Rept.*, Dept. Interior, Canada, 1903, pt. 8.

[2] Ernest Howe, *op. cit.*

4. The longitudinal ridges seen at the upper ends of many of the rock glaciers can often be followed directly to an active talus slope (Figs. 3 and 7).

5. Nowhere have the talus slopes at the heads of the cirques been able to form any considerable accumulations on the surface of the rock glaciers. This seems to be very strong evidence that the talus

FIG. 8.—A small rock glacier north of Sourdough Peak. The characteristic steep lower face of these features is well shown.

has moved on down the valley as fast as it has been supplied (Figs. 3 and 7).

6. In all of the best examples of rock glaciers there is a steep slope at the lower end where the gently sloping surface of the upper portion breaks down at the edge at an angle as steep as the talus will lie. Over this steep face the rock fragments are fresh, while the talus on the surface above this slope is usually lichen covered. This seems to show that the material is moving forward fast enough to prevent erosion of the lower end from reducing it to a low, graded slope (Fig. 8).

FIG. 9.—Rock glacier in McCarthy Creek valley (Fig. 1, No. 4). It terminates below at the mouth of the hanging valley in which it lies, this being the point at which the interstitial ice fails to make possible a slow glacier-like movement. The material from the end of the rock glacier has streamed down to form a well-developed talus cone. Photo by F. H. Moffitt.

7. In the fine example on the west side of McCarthy Creek (Fig. 1, No. 1), the creek, a swift stream of large volume, is now actively cutting into the lower end of the rock glacier, which has been in existence long enough for large spruce trees to grow upon its surface. Nevertheless, the creek has so far been unable to do more than keep a narrow channel open along the foot of the rock glacier (Fig. 6).

FIG. 10.—Rock glacier at head of White Creek. The detritus from the two sides of the rocky island flows together to form a single stream below it.

Yet there is no evidence that the rock glacier ever extended the 75 feet farther east which would have carried it to the rock bluff on the east side of the valley. It seems unusual that this mass of material, if it came down with a rush, should have failed by just the width of the creek to cross the valley, and also that the stream, which is now actively cutting into the face of this rock glacier, has been unable to do more than keep its channel open. It appears as much more probable that the slowly advancing edge of the rock glacier has been removed by the stream as rapidly as it has moved forward.

8. There is no evidence that important landslides have taken place

in this region, if these features are not landslides. None were seen below the miles of prominent, steep cliffs of the area, though ordinary talus cones are abundant.

9. One rock glacier, in a western tributary of McCarthy Creek (Fig. 1, No. 4, and Fig. 9), shows all the characteristics of a typical rock glacier at its upper end, but at the mouth of the hanging valley on which it lies, it streams down to McCarthy Creek as a very perfect talus cone. If it had come down suddenly as a landslide, no such perfect talus cone would have been formed. The presence of the talus cone indicates that the material of which it is composed was supplied slowly, thus enabling the cone to build up symmetrically. The talus cone is still being supplied with material by the rock glacier, as may be seen in the figure from the way in which the talus from above is invading the patch of alder bushes on the side of the cone.

10. Wherever two rock glaciers in adjacent cirques join below to form a single flow, the point of junction shows that the two branches have flowed together synchronously without any evidence that the flow from one branch has come down and overridden that from the other (Fig. 10).

THE GLACIAL LAKE MISSOULA[1]

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The object of this paper is to show that in comparatively recent time an ice-dammed lake filled a large part of the drainage basin of the Clark Fork in northwestern Montana.

To prove the existence of the lake is set forth what evidence has been found in the literature of this region together with a contribution by the writer, whose observations, made at odd times during the past decade, were confined mainly to the Missoula and Bitter Root valleys.

Belief that the lake was ice-dammed was sugggested by certain of the phenomena of this area, but is based mainly on information derived from the writings of others, from which also the probable location of the dam is determinable.

The writer is indebted to Mr. F. C. Calkins, of the United States Geological Survey, for suggestions and criticism.

As long ago as 1885 Professor Chamberlin[2] noted a curious phenomenon in the Flathead lake region that he aptly describes as "a series of parallel watermarks of the nature of exceptionally slight terraces sweeping around the sides of the valley and encircling the isolated hills within it, like gigantic musical staves."

In the vicinity of Missoula similar phenomena have been observed by Professor Salisbury[3] and are noted by Douglass[4] who mentions that "in the Missoula and Bitter Root valleys on the mountain sides and along the foothills are level lines or small terraces, evidently shorelines, formed by the dashing of the waves"; and a brief reference to

[1] Published by permission of the Director of the United States Geological Survey.

[2] T. C. Chamberlin, "Administrative Report," *U. S. Geological Survey, Seventh Ann. Rept.*, 1885–86, 78.

[3] Personal communication.

[4] Earl Douglass, *The Neocene Lake Beds of Western Montana*, published by Montana University, 1899, 10, 11.

them is made by Wood[1] who records that "at Missoula . . . . around the mountains a series of beaches or beach lines extend. . . . ."

The photograph of Mount Jumbo (Fig. 1), a well-known landmark at the mouth of Hell Gate Canyon, brings out more plainly than any written statement could the striking horizontality of these parallel lines. The partly melted snow rather emphasizes them;

FIG. 1.—Hell Gate Canyon, Mount Jumbo, from near Northern Pacific dépôt, Missoula.

still when the ground is entirely bare they can be plainly seen from the city, and have been interpreted by some of the pioneer inhabitants as "old buffalo trails." At close range it is difficult to locate definitely any but the more prominent "trails," the highest of which has an elevation above Missoula of 1,000 feet or 4,200 feet above sea (this and the subsequent elevations as given were determined by aneroid).

University Mountain (Fig. 2), the opposite sentinel of the Hell Gate, exhibits on its western slopes a series of "trails" that are

[1] Herbert R. Wood, "Glaciation in Western Montana," *Science*, XX (1902), 162.

clearly seen to be a continuation of those of Jumbo. From here they may, with many interruptions, be traced to the south along the eastern slopes of the Bitter Root Valley as far as Skalkaho Creek. Again, similar horizontal lines may be seen on the valley's western slopes north of Lo-Lo Fork in situations nearly free from timber. South of Lo-Lo Fork, if they exist, they are obscured by the forest clothing the foothills of the Bitter Root range. Elsewhere, in the

FIG. 2.—University Mountain, from University Avenue, Missoula.

northern slopes of the Missoula Valley below the city of Missoula, and of the Jocko Valley near the Flathead agency, similar "trails" have been noted from a distance. Farther down along the main Clark Fork Valley the slopes are steeper and rocky, and to a great extent timbered. Here the "trails," if they exist, have apparently not as yet been seen, but certain phenomena of this region, as will appear later, may have an intimate relation to them. From unpublished observations of Mr. F. C. Calkins in this area it appears that in the valley of Vermilion Creek an extensive gravel flat trenched by the stream is found at 4,000 feet (aneroid) elevation, and that similar

but less extensive deposits are developed at about the same elevation in small canyons opening into the Clark Fork Valley between Vermilion Creek and Thompson Falls.

East of the town of Stevensville a chain of rounded hills projects westward some 5 or 6 miles into the Bitter Root Valley as a spur from its eastern wall. This spur as a whole descends gradually from an elevation of 6,500 feet to about 3,600 feet where its steeply tilted quartzites disappear beneath the horizontally bedded clays, sands, and gravels that form the valley terraces or "bench lands," which bear a

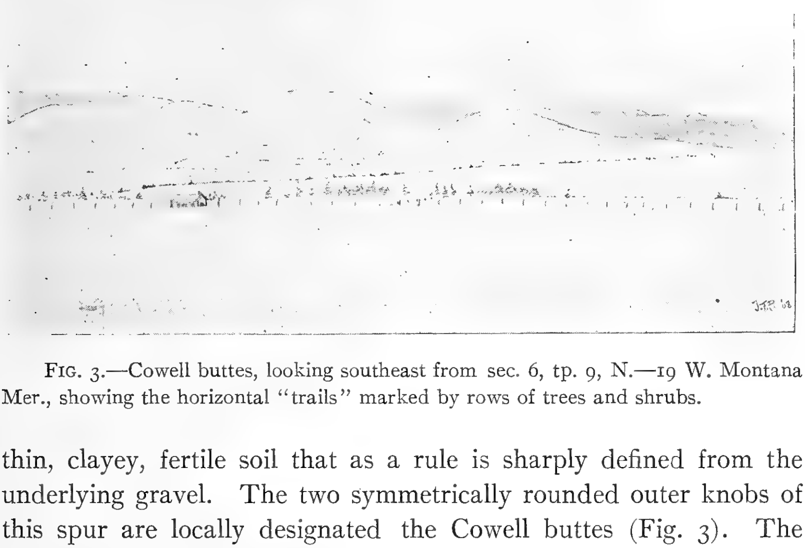


FIG. 3.—Cowell buttes, looking southeast from sec. 6, tp. 9, N.—19 W. Montana Mer., showing the horizontal "trails" marked by rows of trees and shrubs.

thin, clayey, fertile soil that as a rule is sharply defined from the underlying gravel. The two symmetrically rounded outer knobs of this spur are locally designated the Cowell buttes (Fig. 3). The westernmost or first butte attains an elevation of 4,450 feet; the second butte 4,750 feet, while the saddle between is 4,250 feet above sea. The "trails" are well developed on the north and northwest slopes of these buttes; the one at 4,200 feet elevation, above which they apparently fail, is comparatively prominent and its cross-section resembles that of a neglected road grade. The upper bank is broken down but still definable, and the "road bed" eight or ten feet wide merges gradually with the steeper slope below. The sandy soil of this "road bed" is much deeper than that of the slope above and contains numerous subangular to smooth rounded pebbles of quartzite

that in the slopes above are wanting. These pebbles range in size up to four or five inches in diameter and, together with larger masses of quartzite associated with them and possessing rounded edges, are undoubtedly waterworn. Among them no pebbles of a material differing from the quartzite bed rock of the immediate vicinity are found. This "trail" can be easily followed around the north slopes of the buttes, tracing a deep re-entrant angle as it curves around the head of the ravine leading north from the saddle. Here the pebbly deposit gives place to a more extensive one of fine, slightly yellowish, quartz sand, that in one place has been channeled by a rain gully to a depth of eight or ten feet.

Below the 4,200-foot contour the slopes exhibit a succession of parallel trails, exact counterparts apparently of those of Mount Jumbo, except that many of them are conspicuously marked by rows of trees and shrubs. One at 3,700 feet elevation is more than ordinarily prominent. It might at one place be easily mistaken for an abandoned wagon-road along which a row of trees had been set. Its cross-section is similar to that of the one at 4,200 feet, but of larger proportions, the "road bed" twelve to fifteen feet wide being likewise formed of a deeper soil than is found upon the adjacent slopes, containing waterworn pebbles and quartzite fragments.

Just below this contour the quartzite disappears beneath the incoherent sediments of the "bench lands" upon which the series of "trails" still continue to be faintly exhibited down nearly to the river's flood plain.

Douglass[1] describes these benches as beds of sand, gravel, and volcanic ash of Miocene age in part. Remnants of the "trails" are not only preserved upon open slopes of this easily eroded material, but upon the sides of the ravines that dissect it, showing that time since the "trails" were formed has been too brief for any material alteration of the topography by erosion.

On the northern slope of the first butte at about 4,100 feet elevation a large subangular bowlder of gneissoid granite rests upon the surface. It has a volume of perhaps five cubic yards. Several similar bowlders have been noted in the neighboring basin of Three-Mile

[1] Earl Douglass, "A Geological Reconnaissance in North Dakota, Montana, and Idaho, etc.," *Carnegie Mus. Annals*, V (1909), 264, 265.

Creek, and elsewhere in the eastern half of the Bitter Root Valley but in no case at a greater elevation than that recorded.

These bowlders are clearly seen to be erratics, not only from their haphazard distribution, but from the fact that their parent rock is not to be found anywhere in their vicinity nor even in the mountains that form the valley's eastern wall from Skalkaho Creek north.

A strikingly similar rock is, however, the prevailing type of the opposite Bitter Root range.[1]

South of Hamilton in front of the canyons of Lost Horse, Rock, and other creeks heading in this range, moraines extending down to 4,000 feet elevation are found.[2] It is perhaps needless to add that elsewhere the Bitter Root Valley has not been glaciated.

The foregoing phenomena as a whole seem explainable only as the records of an extinct lake or sea. The old "buffalo trails" are the existing remnants of its wave terraces. Its high level was approximately 4,200 feet above sea. At this stage the site of the present city of Missoula was 1,000 feet under water, and glaciers from the Bitter Root range south of Hamilton reached the lake, setting bowlder-laden icebergs afloat upon it. One of these bergs grounded on the prominent cape formed by the Cowell buttes.

During the lake's halt at this level its waves worked considerable fine material into the head of the small bay or cove between the buttes, the remnant of which is still to be found in the upper course of the ravine descending from the saddle. Sediments that settled from this lake are believed to be the main source of the soil referred to on p. 378, to which the agricultural value of the "bench lands" is due. The gravel flats observed by Mr. Calkins in some tributary valleys of the Clark Fork are explainable as delta deposits in a lake. The lake receded gradually, recording many brief halts and a comparatively long one at 3,700 feet.

Douglass[3] suggests "that the water cut with comparative rapidity through its barrier in geologically recent times."

[1] Waldemar Lindgren, "A Geological Reconnaissance across the Bitter Root Range and Clearwater Mountains in Montana and Idaho," *Professional Paper, U. S. Geol. Survey*, No. 27, 42–47.

[2] *Ibid.*, 51–55, and Plates I and X.

[3] Earl Douglass, *The Neocene Lake Beds of Western Montana*, published by Montana University, 1899, 11.

In order to understand the problem of the locality of the dam it is necessary to glance briefly at the topography of northwestern Montana and the adjacent panhandle of Idaho. From the map (Fig. 4) it appears that that portion of Montana west of the continental divide

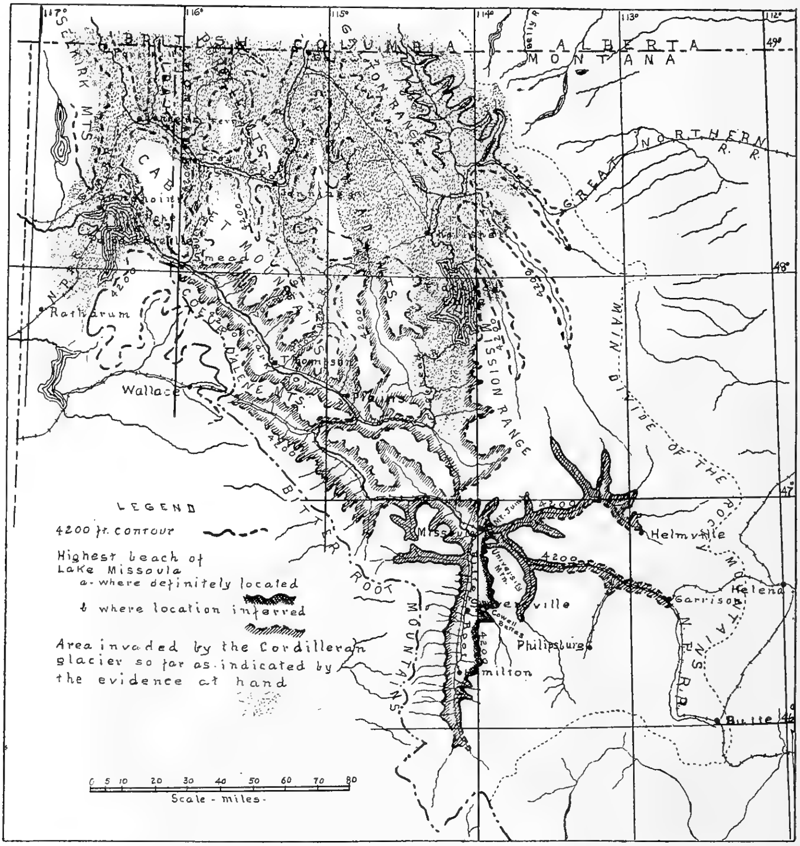


FIG. 4.—Map of northwestern Montana and adjacent portions of Idaho compiled from the U. S. General Land Office maps of Idaho and Montana, topographic sheets of the U. S. Geological Survey, etc.

is largely occupied by an irregular depression, drained by Clark Fork of the Columbia River. If this depression were filled with water to the 4,200-foot contour, the lake formed would be effectively imprisoned on the east and south by the main divide and on the southwest by the Bitter Root and Cœur d'Alene mountains, but to the northwest no

continuous barrier exists, a partial one only being afforded by the detached Cabinet, Flathead, and Galton ranges. Between the latter and the continental divide the valley of the upper Flathead River at the 49th parallel sinks slightly below the given plane, and continues, as a depression (the Rocky Mountain trench of Daly),[1] a great distance northwest into British Columbia.

Between the Galton range and Cabinet Mountains is a considerable area which, although partly occupied by the Flathead Mountains, affords two broad passes through which the water would escape to the Kootenai Valley. South of the Cabinet Mountains, the Clark Fork Valley is depressed at the Idaho-Montana boundary 2,100 feet below the 4,200 level. At this point the valley is rather constricted, its cross-section showing a width of three miles near the river level, and about seven miles at 4,200 elevation.

Of special interest to the problem at hand are three north-south depressions that join the Clark Fork and Kootenai valleys. The largest and most important of these is the Pack River or Kootenai Pass through which the Great Northern Railway crosses from Bonners Ferry on the Kootenai to Lake Pend d'Oreille. It is a rather broad, deep valley whose highest point is about 150 feet above lake Pend d'Oreille and is in reality, as shown by Calkins,[2] a part of the Purcell trench, a depression extending northward 200 miles beyond the 49th parallel.

The two smaller trenches cross the Cabinet Mountains east of this one, the Bull Lake trench[3] affording an easy pass with only 700 feet climb, between Smead on the Clark Fork and Troy on the Kootenai, and, farther east, a depression crossing the same mountains between Plains and Jennings. From the foregoing it appears that at the present time a barrier of sufficient height across the depressions just described would restrain a lake in the drainage basin of the Clark Fork, whose waves would terrace the 4,200-foot contour.

This would also be the case in Pleistocene time if the physiography

[1] Reginald A. Daly, *The Nomenclature of the North American Cordillera between the 47th and 53d Parallels of Latitude, Geog. Jour.*, XXVII, No. 6 (1906), 596–98.

[2] F. C. Calkins, "A Geological Reconnaissance in Northern Idaho, and Northwestern Montana, *Bull. U. S. Geol. Survey*, No. 384 (1909), 16.

[3] *Ibid.*, 15.

of this region was then the same as now. This is for the purposes of argument assumed to be essentially true, such crustal warping and modification of the surface by erosion as have occurred during or since that time being, as indicated by the evidence at hand, insufficient to have seriously altered the topography of this region.

The evidence of icebergs, together with the apparent recency of the lake and the variable height of its surface, connect this lake with the glacial period, and readily lend themselves to the suggestion that its dam was of ice.

Bailey Willis has suggested that this was a Pleistocene lake dammed by a glacier.[1] Many years ago Professor Chamberlin conceived the idea of a glacial dam and furthermore tentatively suggested that its location was in the Pend d'Oreille region with outflow by way of Spokane.[2]

While there has been some local glaciation in the Cœur d'Alene and Cabinet mountains[3] it is evident that these small glaciers were inadequate to have themselves formed the dam, although they may have aided in its production.

That British Columbia was formerly buried under a vast accumulation of ice, generally referred to as the Cordilleran ice-cap, has been made known by the writings of Dawson and others. It appears that south-flowing portions of this ice-cap were even at the 49th parallel of great depths.[4] Its margin was markedly lobate, south-flowing tongues having occupied every large valley that crosses the International Boundary between the Cascade Mountains and the continental divide. To this ice invasion the "trenches" characteristic of this region owe, in a certain measure, their form and fairly constant depth.

While the limits of these great valley glaciers which crossed the boundary west of the Idaho panhandle are fairly well known, knowledge of those east of that point is more or less fragmentary. Some

[1] Earl Douglass, *The Neocene Lake Beds of Western Montana*, published by Montana University, 1899, 11.

[2] Personal communication.

[3] F. L. Ransome and F. C. Calkins, "The Geology and Ore Deposits of the Cœur d'Alene District, Idaho," *Professional Paper, U.S. Geol. Survey*, No. 62, 15, 57; and F. C. Calkins, *op. cit.*, 15.

[4] R. A. Daly, *Can. Geol. Survey, Summary Report*, 1903, 93; *ibid.*, 1904, 95.

idea of the great depth near the 49th parallel of the one that flowed south through the Rocky Mountain trench may be gained from the fact that here it overflowed eastward across the continental divide through Ahern and other passes at the head of Belly River.[1]

The eastern or upper Kootenai Valley held another great south-flowing glacier.[2] At Kalispell, about sixty-five miles south-southeast from the boundary at the point just referred to, the ice was 3,000 feet deep, or its surface nearly 6,000 feet above sea, and came from the north-northwest.[3]

This lobe, probably reinforced by that of the upper Flathead Valley, flowed southward across the Flathead lake region, reaching, as indicated by the observations of Professor Elrod,[4] to the Jocko Valley. A deep glacier flowed south through the Purcell trench, extending at least to the southern end of Lake Pend d'Oreille.[5] At the north shore of this lake, ice is shown by Calkins[6] to have been about 2,500 feet deep.

The same author has also noted the glaciation of Clark Fork Valley above Lake Pend d'Oreille in the vicinity of Bull River,[7] and his observations, with those of Wood,[8] indicate the ice to have been at least 2,000 feet deep. Bull Lake trench probably supported another deep ice-stream[9] that may have been a branch from the Purcell lobe at Bonners Ferry. There is also evidence to indicate that south-flowing ice occupied the Kootenai Valley above Libby,[10] and also the Plains-Jennings depression.[11]

[1] G. E. Culver, "Notes on a Little-known Region in Northwestern Montana," *Trans. Wis. Acad. Sci.*, VIII (1891), 204.

[2] R. A. Daly, *Can. Geol Survey, Summary Report,* 1904, 95.

[3] R. D. Salisbury, "Glacial Work in the Western Mountains in 1901," *Jour. of Geol.*, IX, 724.

[4] M. J. Elrod, "The Physiography of the Flathead Lake Region," *Bull. University of Montana*, No. 16, 202.

[5] T. C. Chamberlin, *Seventh Ann. Rept. U. S. Geol. Survey*, 1888, Plate VIII, 178, 179, and Fig. 15; *ibid.*, "Administrative Report," 1885–86, 78; and Bailey Willis, "Changes in River Courses in Washington Territory, Due to Glaciation," *Bull. U. S. Geol. Survey*, No. 40, 8.

[6] F. C. Calkins, *op. cit.*, 31.

[7] *Ibid.*

[8] H. R. Wood, "Glaciation in Western Montana," *Science*, XX (1902), 162.

[9] F. C. Calkins, *op. cit.*, 31, and unpublished field notes.

[10] R. D. Salisbury, *op. cit.*, 723, 724.

[11] H. R. Wood, *loc. cit.*

It appears then that escape of the water through the more northerly passes or by way of the lower Kootenai was effectually blocked by ice-barriers of much more than the necessary height.

One of the very largest of these lobes flowed south through the Purcell trench and dammed the only remaining avenue of escape, the Clark Fork Valley. From 7,300 feet elevation at the 49th parallel the glacier's surface sloped down to about 4,200 feet here, where it forced the lake to seek its outlet.

While the vagueness and close spacing of most of the lower beaches seem to depend on the inconstant level of an ice-dam that formed one wall at least of the outlet, the more prominent ones, indicating constancy of level for a relatively long period, suggest that the outlet may at times have been a col in some opposing spur from the Cœur d'Alene Mountains. Until the ice, by rising, should invade such an outlet, or by sinking below it should capture its flow, the water level would be comparatively stable.

Reviews

Traité de géographie physique.—Climat—Hydrographie—Relief du sol—Biogéographie. By EMANUEL DE MARTONNE. Paris: Librairie Armand Colin, 1909. 8vo, viii+910 pp., 396 text figs. and maps, 48 phot. plates, 2 colored planispheres.

This work, as stated by one reviewer, is a mine of information with a wealth of useful illustrations. As stated in the author's preface, it aims to put the educated public on the track of important geographic publications, and to give to the specialist a general treatise that will aid in rounding out and properly orienting his special lines of research. Each subject discussed is followed by a full list of recent works bearing upon it, to be found in the French, German, and English languages, and occasional works in other languages. Topographic and other maps of value in illustration of the features discussed are cited by name or number, and include many from the United States as well as from most of the European countries, and a few from Africa and India.

Many of the illustrations are artistic sketches made by the author from nature. Representation in three dimensions is also a notable feature of the illustrations. The wealth of illustrations and of references is combined with a clear and vivid presentation in the text. It will be a useful work for schools as well as for the specialists and the educated public. The author's experience as a teacher as well as a field investigator counts in the preparation of this comprehensive volume. The author's special lines of investigation, glaciers and physiographic features, are handled with exceptional clearness, but the work shows evidence throughout of painstaking collaboration and treatment. As a basis for the discussion of certain subjects the classic works of Hahn, Haug, de Margerie, Angot, and others are freely drawn upon:

The first 72 pages deal with the form and situation of the earth as a planet, and the modes of representing the terrestrial sphere by various projections. The author recommends, and uses in this work, the Mollweide projection for maps of large area, but for topographic maps with a scale of 1:100,000 or less the use of polyconic projections is recommended. He deprecates the use in school atlases and wall maps of the Mercator projection with its exaggeration of polar lands, and urges that the projection be clearly stated on all maps for school use.

The elements of physical geography are discussed very briefly (pp. 73–96). Physical geography is defined as the science of the extent and reciprocal reactions of the phenomena by which the surface activity of the globe is manifested. It deals with an active or living surface, and its particular horizon is at the contact of the gaseous envelope with the solid and liquid parts of the earth's surface. The four main subjects of the work, as stated in the title, are "Climate, or the Physical Geography of the Air," "Hydrography, or the Physical Geography of the Water," "Terrestrial Morphology, or the Physical Geography of the Land," and "Biogeography," which brings out the relation of life to the various physical features.

Under "Climate" (pp. 97–251) are considered three elements, temperature, winds, and degree of humidity, the last named embracing evaporation, humidity, cloudiness, and rainfall. The state of climatological knowledge is set forth by a map (Fig. 38), a revision of one given in Bartholomew's *Physical Atlas*, while the various types of climate are presented on a colored planisphere prepared by the author. This represents for the entire globe 27 types of climate, 9 of which are equatorial and tropical, 5 subtropical, 6 temperate, 3 cold, and 4 desert types. Of the desert types 2 are warm climate (Peruvian and Saharian) and 2 cold climate (Patagonian and Aralian).

Under "Hydrography" (pp. 257–365) the first chapter deals with the ocean, and considers the features of the basins and the temperature and salinity of the water. The second chapter deals with the ocean currents. Then follow in turn chapters on the seas, the lakes, and the streams. Under rivers, attention is given to the relation of the sources to their regimen, and to various other problems of fluvial regimen, climatic, geologic, physiographic, and also the influence of the various types of vegetation.

Under "Terrestrial Morphology" (le relief du sol) the first chapter sets forth the relative value of various classes of topographic maps in giving a knowledge of terrestrial forms. Such maps, supplemented by sketches and views, are the principal sources of knowledge of the earth's features. An analysis is then given of the degree of complexity exhibited by the various forms, and the importance of erosion as a modeling agent is brought out. The several dominating forms of erosion and deposition as distributed on the face of the earth are set forth in a very instructive map (Fig. 172) as follows: (1) mechanical disaggregation with stream transportation, (2) mechanical disaggregation with wind transportation, (3) mechanical disaggregation with accumulation (in interior basins with dry climate), (4) areas of fluvial accumulation, (5) areas of eolian accumulation, (6) loess accumulation, largely eolian, (7) predominating chemical decomposition

with fluvial erosion, (8 and 9) regions of present and past glacial erosion, (10) regions of Quaternary glacial accumulation.

The chapter devoted to the cycle of fluvial erosion is well illustrated by photographs and sketches and sections of maps. Another chapter deals with the influence of the physical properties of the rocks in giving certain features. In this chapter is also discussed the subterranean drainage and karst topography. One chapter each is devoted to the tectonic influences and the volcanic outflows in producing certain features. Following this comes a somewhat detailed discussion of the evolution of drainage systems, in which the nomenclature suggested by Davis is used to some extent. This chapter is exceptionally full of diagrams in three dimensions, prepared by the author, which bring out the stratigraphic conditions as well as the surface features.

A chapter on paleogeography with notions concerning the geologic evolution is perhaps more subject to question than any other part of the volume. The map of the continent of Gondwana (Fig. 271) (modified from Frech), which represents a land area stretching from Australia past Africa to South America in Permo-Carboniferous times, will scarcely be accepted by those who believe in the permanence of the ocean basins. It seems to be based largely upon the distribution of the Glossopteris and kindred plants in Permian time over this wide range of the earth's surface. In addition to this Permo-Carboniferous map of the earth there is one for the Upper Cretaceous (Cénomanien) and the Quaternary; the latter represents also the glaciation. In addition to these are representations of European Miocene and Pliocene distribution of land and sea. The mountain-making movements of Europe, in accordance with ideas of Suess and Marcel-Bertrand, are also brought out in two sketch maps (Figs. 270 and 273).

A chapter is devoted to glaciers and glacial topography (pp. 600–647), which is illustrated by a large number of excellent Alpine photographs and by numerous sketches by the author both of European and American features. These sketches as well as the maps and photographs and descriptions bring out the results of glacial erosion very clearly. The features of accumulation are treated more briefly. A map showing the extent of Quaternary glaciation in the United States (Fig. 298), prepared by Chamberlin in 1894 for Geikie's *Great Ice Age*, should have been replaced by a map showing more recent results of mapping of moraines in the United States. It also erroneously places the Illinoian glaciation in central Iowa.

A chapter is devoted to eolian action and desert forms and another chapter to the coastal topography.

The final subject, "Biogeography," is treated with great fulness (pp. 709–862), and takes up not only the general principles of biogeography, but goes into considerable detail in reference to plant communities in various climatic areas, tropical, subtropical, and temperate, in Alpine regions and Arctic zones, and in desert regions both cold and warm. Under "Zoögeography" the aquatic fauna is discussed in relation to its distribution in deep sea or on continental shelves, and in relation to varying degrees of salinity and warmth of water. The terrestrial fauna is considered in reference to physiographic conditions, food conditions, and climatic conditions.

F. L.

Yorkshire Type Ammonites. Edited by S. S. BUCKMAN. Part I. London, William Wesley & Son.

In this work the editor has undertaken to republish, with illustrations and critical notes, the descriptions of Lias Ammonites from Yorkshire, England, which were originally described by Young and Bird, and by Martin Simpson.

The original publication of Young and Bird, in 1822, appeared under the title *A Geological Survey of the Yorkshire Coast*, "Describing the Strata and Fossils Occurring between the Humber and the Tees, from the German Ocean to the Plain of York, by Rev. George Young, A.M., and John Bird, artist." A second edition, with many alterations from the first, appeared in 1828.

Martin Simpson's first work appeared in 1843 under the title *A Monograph of the Ammonities of the Yorkshire Lias*, "Containing the Specific Characters and Popular Notices of More Than 100 Species; with References to the Particular Beds and Localities Where Each Is to Be Found; Including, Also, the Two Species of Nautilus. Described from Nature, by Martin Simpson, Curator to the Geological and Polytechnic Society of the West Riding of Yorkshire and Late Keeper of the Whitby Museum, Lecturer on Geology, etc." In 1855 a second work by the same author appeared under the title *The Fossils of the Yorkshire Lias; Described from Nature*, "with a Short Outline of the Geology of the Yorkshire Coast. Illustrated with Sections; and Intended as a Guide to Strangers. By M. Simpson, Lecturer on Science, and Curator of Museums." A second edition of this work was published in 1884.

These works, highly important as they are, have never received proper consideration by students of Lias Ammonites, chiefly because they are for

the most part difficult to procure, and are in large measure inaccessible. In the fine discrimination of specific forms Simpson seems to have excelled, but his descriptions are unaccompanied by illustrations, which has rendered them difficult to follow.

In his republication of the descriptions of these forms the editor has had access to the original types, which will be illustrated, and with his critical notes the contribution will be of inestimable value to all students of this highly interesting fauna. For the preparation of such a work as this the editor is the most eminently fitted of any English paleontologist. The work is planned to be complete in about 16 parts of from 12 to 16 plates each. The first and second parts are now published, containing 23 plates with the descriptions of 22 species.

S. W.

An Introduction to the Geology of Cape Colony. By A. W. Rogers, Sc.D., and A. L. DuToit, A.B. 2d ed. London: Longmans, Green & Co., 1909. Pp. 491, 25 plates, 29 text figures, and a colored map.

The first edition of this work appeared in 1905. During the five years which have passed since its appearance considerable advances have been made in the knowledge of Cape geology, and in the light of this new information, the work has been revised and partially rewritten. The most notable changes occur in those parts of the book which deal with the ancient rocks in the north of Cape Colony, with the Dwyka conglomerate, the correlation of the Karroo system, the intrusive dolerites, and the famous volcanic pipes. The revision also embraces important advances in paleontology. An entirely new chapter on "Economic Geology" has been added, while, in order to keep the book about the same size as before, the less important parts of the first edition have been reduced or omitted.

The chief formations of Cape Colony are the old pre-Cape rocks, the Cape system, Karroo system, and the Cretaceous, and to these the bulk of the volume is devoted, with, however, chapters on the Tertiary-Quaternary deposits, intrusive dolerites, the diamondiferous volcanic pipes, geologic history of the colony, and economic geology. The greatest emphasis has been placed upon the Karroo system which, on account of its peculiar and profoundly significant features, is of special importance to geologists and paleontologists the world over. A chapter on the reptiles of the Karroo is contributed by Professor Broom.

R. T. C.

History of the Clay Working Industry in the United States. By HEINRICH RIES, PH.D., AND HENRY LEIGHTON, A.B. Pp. 270, with 8 plates and 3 figures. New York: John Wiley and Sons, 1909.

The arrangement of this admirable book is very simple. In the first part the history of the clay-working industry is treated by products; in the second part the development in each state is taken up in alphabetical order. This manner of treatment necessitates more or less repetition, but it permits the presentation of a more connected chain of events for each district.

A great amount of detailed statistical information has been gathered together and made available for use. Through a historical record of isolated facts, figures, and statistics, the authors of this treatise have such a thorough command of the subject that they have instilled much of their own enthusiasm into its pages.

R. T. C.

Norsk geologisk tidsskrift (Norwegian Geological Magazine), Vol. I. Kristiania: J. O. Brögger, bookseller, 1910.

The geologists in Norway have formed an association, "Norsk geologisk Forening," in Kristiania and published the first volume of a magazine. The chief contributor is the well-known student of petrography and of the geology of ore bodies, J. Vogt, who writes in German. His important article on anchi-eutectic and anchi-monomineral eruptives is published here.

Th. Vogt (son of J. Vogt) has written a mineralogical article on barytes. A. Hoel communciates new observations on the geology of Spitzbergen (Norwegian with summary in English). The rest of the papers treat of Norwegian geology. All but two have English summaries.

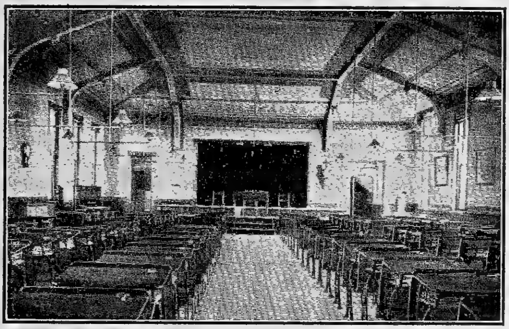
HANS REUSCH

Why Contagious Diseases Are So Quickly Transmitted in Schoolrooms.

A SURE METHOD OF PREVENTION

THE time is not far distant when action will be taken by the Boards of Health in every city, town and village of this country, to *compel* the elimination of the dust in schoolrooms by proper care of the floors.

Educators are rapidly coming to a realization of the fact that "dust" is the principal cause of disease transmission among school children. The floors in schoolrooms are bare, and when large numbers of pupils are assembled the constant motion of feet produces a continuous circulation of dust. These dust particles are composed of vegetable, animal, and mineral material finely pulverized. From tests made with dust collected from schoolrooms and other places of public assembly, it has been found that with the dust were uncountable myriads of disease germs—bacilli of Tuberculosis, Typhoid Fever, Diptheria, Pneumonia and other dangerous diseases. These experiments afford irrefutable proof of the dangers arising from dust and explain why contagious diseases are so quickly transmitted in schoolrooms.



To do away with this menace—to avoid the dangers of dust poisoning, it is not only necessary to provide a system of ample ventilation, but also to *treat the wood floors* in such a way that dust and germs cannot pollute the atmosphere.

Standard Floor Dressing has proved itself a perfectly satisfactory dust-preventive. By keeping the floors at a proper degree of moisture the dressing catches and *holds* every particle of dust and every germ coming in contact with it. Tests have been conducted to determine the quantity of dust and number of organisms which would settle on a given surface. Results prove that the dust from floors treated with Standard Floor Dressing is twelve times greater in weight than that collected from *untreated* floors. The inference is obvious—the balance of disease-laden dust in the rooms with *untreated* floors *was circulating through the air*, because even after settling on the floor every current of air would disturb it and start it afloat again. Another test proved that dust once settled upon a floor treated with Standard Floor Dressing remained there, and a bacteriological examination demonstrated that 97½% of all the disease germs caught with the dust were destroyed outright.

Such tangible proofs should convince anyone that Standard Floor Dressing is invaluable for use in schools as a preventive of disease.

In addition to its germicidal properties, Standard Floor Dressing does splendid work in keeping the floors themselves in a state of excellent preservation. It prevents the wood from splintering and cracking and renders sweeping and caretaking a comparatively easy task.

While Standard Floor Dressing is not intended for use *in the home*, it *is* intended for use in schools, hospitals, sanitariums, stores, and public buildings of every description.

It is sold in convenient form by dealers in every locality, and may be had in full barrels, half-barrels, one gallon, and five gallon cans.

Three or four treatments a year give best results, and when spread with the patent *Standard Oiler* may be used very economically. The Oiler distributes just the right amount to every part of the floor, and as the dressing does not evaporate, one application will last for several months.

Standard Floor Dressing is now being used with remarkable success in thousands of schools, colleges, stores, and public buildings, and we have yet to hear of an instance where the dressing has failed to reduce the circulating dust and kill the floating disease germs. All we ask is an opportunity to *prove* the merits of Standard Floor Dressing.

In order to convince those who may be skeptical, and those who are really interested, we are making an extraordinary offer. Select one room or corridor in any public building under your supervision and we will dress the floor with Standard Floor Dressing AT OUR OWN EXPENSE—the test will not cost you one cent.

To localities far removed from our agencies, we will send free sample with full directions for applying.

Correspondence is desired with those responsible for the care of schools and public buildings. Our book, "Dust and Its Dangers," with testimonials and reports is sent free on request.

STANDARD OIL COMPANY
(Incorporated)

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THE

JOURNAL OF GEOLOGY

JULY–AUGUST, 1910

NOTES ON THE GEOLOGICAL SECTION OF MICHIGAN[1]

PART II. FROM THE ST. PETER SANDSTONE UP

A. C. LANE
Tufts College, Mass.

INTRODUCTION

An apology is due for the long gap which has elapsed between the publication of Part I and Part II. This is due to the fact that I wished to have the benefit of the work of Professors A. W. Grabau and W. H. Sherzer without trespassing upon their rights. This I can now do[2] though we are not yet in accord as to interpretation. Perfect accord, however, cannot be expected. An advantage is that in the mean time Schuchert's[3] and other paleogeographic studies have appeared. This paper was written before Schuchert's and independently, so that the numerous confirmations of his maps are valuable checks, while discrepancies have not been subject to critical revision. Almost all the places referred to will be found underlined on a map in Vol. V of the *Mich. Geol. Survey*, and detailed references to the facts upon which the statements of this paper are based will be found in the report for 1908.

The second, or upper part of the Michigan rocks here described, including Ordovician and Carboniferous, has peculiar interest in many ways. In the first place it stands as the connecting field between the standard New York and the Mississippi Valley rocks.

[1] Part I appeared in XV, 680, of this *Journal*.

[2] See Grabau's papers in *Science*, No. 739 (1909), 356; *Bull. G.S.A.*, XVII, 567–636; XIX, 540–53.

[3] *Bull. G.S.A.*, XX (1910), 427–606.

In the second place it has not been much disturbed. It is too much to say not at all disturbed, for there is caught in the synclinal fold of Limestone Mountain on Keweenaw Point the Niagaran, so that we are led to infer that notable disturbance took place along the line of the Great Keweenaw fault after the Niagara. There are in the Lower Peninsula also signs of slight foldings at various times. But on the whole the strata lie in one vast little-disturbed *persistent* basin, Schuchert's Ontario Traverse Basin, in a gentle embayment of the great pre-Cambrian boss or shield which curves around them from Wisconsin on the west to Canada on the east. It is possible that at the center of this basin Paleozoic deposition was continuous, perhaps not always marine.

A notable feature is the general fineness of the sediments and absence of conglomerates. These latter are extremely rare. If one overlooks some perhaps autoclastic limestone calcirudites, occasional pebbles of quartz as big as peanuts and in the Marshall a few narrow thin bands of conglomerate containing very little but quartz, he may say there are none. The wide variety of crystalline and igneous rocks which lie only a short distance northeast to northwest are practically absent until, of course, we come to the glacial till, where they are abundant. These facts seem strong grounds for believing that during all the Paleozoic time this great area was neither glaciated nor violently disturbed and uplifted. We ought to have therefore in the Michigan section an ideal place, where the strata are well exposed, to study those universal advances and retreats of the shore-line which must have occurred as the ocean level was raised the world over by filling-in of sediments, or lowered by falling-in of blocks of the ocean floor. It is likely that we can recognize already the broad outlines of Huntington's steady and more unsteady periods as follows:

Relatively Steady	Relatively Unsteady
Jurassic and Cretaceous	Tertiary and Quaternary
Upper Mississippian	Permo-Carboniferous and Triassic (New Red)
Middle Devonian	Upper Devonian (Old Red)
Niagaran	Lower Devonian and Late Silurian
Trenton-Utica	Upper Ordovician Lorraine to Clinton
(Ozarkian ?) Calciferous ?	St. Peter sandstone minor
	Early Cambrian and Keweenawan
Animikie black slate	Palms and Goodrich
Kona dolomite and	Possibly an oscillation below Keewatin
Grenville limestone	

System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rock
QUATERNARY	Pleistocene	Recent Champlain Wisconsin and earlier drift sheets		1110 — 0	Sand, gravel, boulder clay Lake Superior pink clay. Till: boulder clay, sometimes very sandy, again clayey and dark. A gray and red till may in some places be distinguished, an older and a younger
POSSIBLY LATER	Conemaugh	Woodville		110 — 0	Light reddish sandstone and sandy shales
	Pennsylvanian (Upper Pottsville)	Saginaw		400	White sandstone, coal seams, black and white shales; thin bands of limestone and of siderite rare, rarely broken up and found in fragments of the sandstone.
		Parma		170—0	White sandstone and conglomerates, of small white quartz pebbles, brine and sulphates.
		Bayport or Maxville Upper Grand Rapids Upper St. Louis		235—50	Limestones: light and bluish, cherty, also calcareous sandstones.
		Michigan Lower Gd. Rapids Lower St. Louis Osage or Augusta		300—0	Dark or bluish limestones and dolomites with gypsum and blue or black shales: rarely reddish or greenish shales and dark or red sandstones.
		Napoleon Upper Marshall		560 — to	White sandstone: often pyritic, brine or fresh water, sulphates low.
CARBONIFEROUS	Mississippian	Lower Marshall		260	White and red sandstones: peanut conglomerates, sandy shales, whetstones, and blue shales, mudcarbonate of iron, and mica in the formation; generally a red shale at the top and bottom.
		Coldwater Buena Vista		1000—800	Blue shale: with nodules of carbonate of iron especially at the top; sandstone, very subordinate streaks of fine grained limestone, especially on the west side, black shales at the base.
		Sunbury or Berea			
		Berea			White sandstone; brine and salt even near the surface.
	Neo-Devonian	Bedford Antrim (Senecan)		480— 140+	Shale mainly black and always at the base, with huge round balls of calcite; towards the top, blue and black shales.
DEVONIAN	Meso-Devonian	Traverse: Naples goniatite fauna; Petosky limestone; Acervularia beds Hamilton (Erian) Bell and (Marcellus shale)		660 to 50 60	Bluish limestones, dolomites and shales: base a blue or black shale; top generally limestone and rarely reddish.
		Dundee (Ulsterian)		255 to 65–	Limestone: buff and light brown, fiercely effervescent, somewhat cherty.
	Latest Ontarian possibly Eo-Devonian	MONROE: Upper Monroe or Detroit River (Lucas, Amherstburg, Anderdon, Flat Rock)		275 to 0 (a 200, b 20, c 30, d 47)	Dolomites: mainly; the Anderdon formation is limestone; gypsum or anhydrite also occurs, with celestite and sulphur.
		Middle Monroe, Sylvania		440 ? to 30	White sandstone very pure, passing towards the north into calcareous sand-limestone.
	Upper Ontarian	Lower Monroe or Bass Island (Raisin River, Put-in-Bay, Tymochtee, Greenfield)		200 ? 100 + 100 – 100–	Dolomites: at some levels sandy, at others oölitic, often cherty. At the Tymochtee and other levels shaly; anhydrite abundant in the lower parts of the salt basin; Celestite.
UPPER SILURIAN OR ONTARIAN.	Middle Ontarian	SALINA ? (3, 2, 1)		960 to 0	Salt, anhydrite, dolomites, calcareous marls: red and green, more rarely blue and black, shales.
	Lower Ontarian (Niagaran or Manitoulin)	Guelph and Niagara		600 to 270	White dolomites: peculiar whiteness characteristic, often cherty, and with a little quartz sand which sometimes occurs in beds; pure limestone rare.
		Rochester Shale		85 to 0	Blue shale.
		Clinton		130 to 0	Reddish limestones and shales or iron ore.
		Medina and		100 to 0	Red shales, sometimes sandy or green shales.
	Upper Ordovician (Cincinnatian) (Hudson River)	Richmond		150 to 0 ?	Shales, red and blue and sandy; gradual transition at base.
LOWER SILURIAN OR ORDOVICIAN		Lorraine		345 to 215	Shales: blue, sometimes in streaks black, especially towards base.
		Utica		60 to 50	Black shales.
	Middle Ordovician	Trenton (Galena, Platteville ?)		271 to 100 ?	Limestone and dolomite; blue and shaly, or solid shale at base.
		St. Peter		18 to 0	White friable sandstone; or represented by red clay,
OZARKIAN ?	Lower Ordovician	Calciferous			residual top of underlying formation.

ORDOVICIAN

11. *St. Peter sandstone.*—There is no probability that these periods are of uniform length or intensity of oscillation. The unsteady period between the Trenton and Calciferous (Canadic-Ordovicic) appears to be much less important than the great period terminating in the Lake Superior overlap which in Michigan at least may include a good part of Ulrich's Ozarkian,[1] and perhaps earlier (the Keweenawan) during which Michigan was out of water and rent by tremendous volcanic outbursts.

In an emergence sandstone the sand itself, being rehandled along a rising coast, is more likely to be uniform in texture. Its connate water may be fresh at the margin. In many respects the St. Peter sandstone is a typical emergence sandstone as compared with the Lake Superior sandstone and that is one reason why I do not think it extends into the Lake Superior basin. As Schuchert's curve[2] indicates it does not mark so much emergence. My remarks in Part I that the viewpoint of one studying drillings is different from that of one studying outcrops in such a basin as Lower Michigan must not be forgotten. The gaps due to discordances and disconformities are liable to be much greater; the emergence sandstones less at the outcrop that at the center of the basin. Both the St. Peter and the Berea I take to be emergence sandstones in Michigan, and neither of them have been recognized as outcrops, though distinct in some drill records. The base of an emergence sandstone is probably a more definite datum plane than that of a submergence sandstone.

The greatest thickness of the St. Peter seems to be to the southwest. Just outside the state at Marinette, No. 2 well apparently gives 75 feet of it from 325–400 feet. But how rapidly it thins and how irregular it is, is shown by the fact that at Gladstone it was not distinctly recognized, and across the Bay de Noe perhaps represented only by a red clay shale, the weathered surface of the Calciferous dolomite. It seems to fill hollows in the eroded Calciferous quite as in Wisconsin. Farther east it is not known. The Pickford record is imperfect, and in the Neebish samples, if present, it is indistinguishable from the Lake Superior sandstone.

[1] Schuchert, *Science*, XXIX (1909), 630; *Bull. G.S.A.*, XX, No. 20.

[2] *Op. cit.*, Pl. 101.

12. *Trenton limestone.*—Under this head have been grouped, as appears from Foster & Whitney's map, and the text by them (p. 140, Hall and others) equivalents to the Chazy, Birdseye, Black River, and Trenton in its narrower sense of New York. We are thus including all the Mohawkian and the Chazy, the lower half of Schuchert's Ordovicic. Grabau would include all up to the Black River in his Chazyan or Middle Ordovician, and would also combine the Trenton with the overlying Utica. In a general way it is what Bigsby referred to (1823, pp. 195–96) as the "limestone of St. Joseph." He refers to its typical exposures on St. Joseph Island and figures characteristic fauna. He also gives an excellent lithological description, mentioning the characteristic "Birdseye," or as he calls it "knotty," texture of some parts.

Pleading that neither at top nor bottom do our dividing lines exactly agree in time with the New York column, Grabau would suggest a local name like Escanaba. But it is entirely unlikely that the dividing lines are exactly the same at the two ends of the Upper Peninsula—that is, on the Escanaba and St. Mary's rivers where alone it has been, or can be, studied. Still less likely is it that where it has been struck in deep wells at the other end of the state, it is the same. Yet all over this vast area the line of change to black shale (Utica) from limestone or dolomite is well marked and of practical importance. It probably represents not very far from the same time. In fact, why should not a change in sedimentation at this point be due to diastrophism involving an instantaneous or simultaneous change over a wide area, a general retreat of ocean due to a large drop in its bottom somewhere, both shallowing the sea and exposing the land to renewed erosion and so muddying the waters?

For subdivisions we may use the Green Bay wells:

Galena limestone, crystalline, granular	83
Limestone, fossiliferous 55 ft., white 8 ft., dark 9 ft.	72
Alternating blue and brown, crystalline, granular. With the dark base compare the Wisconsin oil rock	225
Sandy limestones, "quartz" 6 ft., limestone 44 ft., quartz 1 ft., limestone 24 ft., compare quartz sandstone at Marinette at 260–275 ft.	75
Wisconsin Trenton (Platteville ?), blue shale and limestone	41
Blue shale 4 ft., black limestone 141 ft., limestone 19 ft., blue shale 4 ft.[1]	

[1] By a numerical slip in the *Annual Report* for 1903, p. 132, it is given as 41 ft.

At Marinette, too, the samples at 290 and 300 to 325 feet are shaly, blue, pyritiferous, and a well near Maple Ridge shows that this blue shaly base is persistent. Beneath it is a marked horizon for water. In the Neebish well, the bluish shalier base is distinct between 158 and 186 to 205 feet, but other correlations can hardly be made. I do not believe that we can yet tell where to draw the line between the Middle and Upper Ordovician on Grabau's latest plan, his Chazyan, and Trentonian-Cincinnatian-Nashvillian, nor divide into the epochs made by Schuchert, though possibly this blue shale may mark the culmination of submergence, the beginning of emergence. It is quite clear that the Trenton, as used in Michigan and generally in the West, corresponds closely with Clarke and Schuchert's Mohawkian, including whatever there may be of Chazy and Stones River (Lowville or Birdseye), Black River, and Trenton.

The section on the Escanaba River is said by Hall to be less than 75 feet (p. 144) and to include 15 feet near the top, gray, meagerly fossiliferous (p. 146). Rominger estimated it at 100 feet. But a close correlation of the various outcrops with well-sections has not yet been made. Until it is, it seems to be conservative in the matter of names.

While Escanaba limestone, suggested by Grabau, is a euphonious term, my impression is that it would be better to use Trenton, the old widely used term, in a broad sense and introduce Escanaba as applicable to some accurately defined subdivision. The triple division above suggested might perhaps be improved for paleontological purposes by transfer of a few feet. I think, however, that the occurrence of a sandy middle member, and especially a blue shaly lower, will be found widespread.

The Trenton limestone marks the culmination of Ordovician depression, when the land masses seem to have been fully buried far and near, while at the same time conditions for animal life were very favorable. As Limestone Mountain on Keweenaw Point shows the Trenton extended much farther than shown on Chamberlin and Salisbury's map (II, Fig. 129, Schuchert's map, 57 to 58). The thickness of the whole Trenton, including the Galena, is best taken from the Wagner wells (1903, p. 134) as 271 feet. The records do not indicate that it thins much to the east. Oil wells in Manitoulin

Island at Gore Bay report it 250 feet thick. I do not know any well in the lower part of the state that has gone through it, but in wells in northwestern Ohio it is said to be over 780 feet thick and in the Carmen well at Petrolia, 602 feet. While called a limestone, in this state it seems to be often dolomitic.

13. *Utica shale* (Eden of Ohio). 50–80 feet.—In many parts of the West geologists have consolidated all the shales over the Trenton as Hudson River, Cincinnati, or Maquoketa. In Michigan we seem well able to separate a black shale below, persistent and fairly uniform, varying in thickness from 50 feet at the north to about 200 feet at the south. It does not seem to be separated by disconformity above or below, and the conditions which produced it, widespread as they were, we may well expect to be universal in the sea in which it was formed. The correlations with the Utica or Eden of Ohio and Utica of western New York seem perfectly satisfactory. The base is well defined, but the line between it and the Lorraine above is not sharp and probably not consistently drawn, and may sometimes have been carried up to the Waynesville, especially as none of the wells are represented by samples every 25 feet or less. Generally the Utica and Lorraine have been grouped together and mapped with the Richmond, also as the Hudson River (Cincinnatian or Maquoketa).

14. *Lorraine or Maysville.*—We must often include with Lorraine the Richmond as well as the Maysville, which we cannot sharply separate from this or the Medina. The beds are abundantly fossiliferous, and their correlation with the "blue limestone and marls" of the Cincinnati and "upper beds of the Hudson River" is attested by Hall, Winchell, and Rominger. The Wagner well shows for the blue beds 150 feet and more, the Pickford well 215 feet, and the breadth of the belt assigned to the Lorraine and the Utica on the maps with a dip of 40 to 60 feet to the mile would indicate 350 to 450 feet. They probably thicken rapidly to the south at first, as Cheboygan well would indicate over 343 feet, while on Manitoulin Island there is but 285 feet between Niagara limestone and Trenton. At the south end of the state the records indicate about 600 feet of shaly beds to be divided between the Utica, Lorraine, Richmond and Medina, say 200 feet Utica, 250 Lorraine, 150 Richmond and

Medina. The Lorraine, therefore, appears to be fairly uniform in thickness throughout the Lower Peninsula except at the extreme north end, where it may have been eroded. The Cheboygan well shows largely limestone. The line at the top is quite uncertain. I may have included beds corresponding to the Indiana Richmond.

15, 16. *Richmond and Medina transition beds.*—This is the period of deposition of coarser matter and residual red clays formed from limestone during a period of continental uplift. Ulrich[1] would class the Indiana Richmond with the Medina and the whole group not with the Ordovician but with that above. I do not doubt that he is right. There is, however, a convenience in grouping it closely with the shales below, since it is often lumped together with them in oil-well drillings. If formed in a period of continental uplift we need not expect to find it spread so far onto the continental shield. Except for a few (26) feet doubtfully assigned to the Upper Medina by Holt and Winchell, it has not been recognized in outcrop, nor was the characteristic red facies noted in the Pickford well. At Limestone Mountain the interval from Trenton to Niagara is not exposed, no Medina has been found. The Cheboygan well shows that though absent or nearly so along the outcrop it increases rapidly to the south, since Alden and I would assign to the Medina the beds pierced by that well about 142 feet of red and green shale. During this period, Richmond to Medina and Clinton, there was a relatively ample supply of iron to the sediments, as the Clinton ores (found in Wisconsin also) show. Cummings has recently described the different horizons in southern Indiana very carefully[2] and agrees with Ulrich that the later Richmond represents the Medina, the culminating of an uplift. With this, Michigan facts are entirely in harmony, though Schuchert brings in a big oscillation in the Richmond for which I have not noted any evidence.

In wells of the region near Ohio, red beds at this point of the column can be identified, but what is noteworthy and significant, the records do not closely correspond. For instance, at Monroe 685 feet and at Toledo 675 feet above the Trenton is the last distinct dolomite sample (Clinton ?), with red and green shales below, whereas

[1] *Science* (1909), 630.

[2] *Thirty-second Report Indiana Survey* (1907), 621, 687.

at Strasburg a few miles off at 534 feet only above the Trenton is dolomite with a very red rock beneath it. No such rocks are clearly identified in the wells in the southwest part of the state, and probably were never deposited. A simple explanation would be that there was some erosion of the underlying formation here as well as along the north border and that the red and the marine part of the Medina was much restricted. Grabau has suggested that these red beds are not marine and includes the Medina as Clinton. There seems, however, to be a gradual transition from the beds below, rather than sudden uplift. Moreover, why, if wholly land beds, should they be restricted to the center and lower parts of the basin?

SILURIAN (ONTARIAN)

Some part of the beds just described may be Ontarian, as Ulrich and Cummings have said, with whose interpretation of the facts Michigan stratigraphy is in entire harmony. If so they should be classed as Medina, but as in many of the records of wells we have to include them with the shale group below, I have preferred to associate the description also.

The term Niagaran as used in Michigan includes, in mapping, Clinton to Guelph. In sections it has been used also in a slightly narrower sense, not including the Clinton.

Bigsby (1823) used the term Manitoulin limestone in an equivalent sense, giving its lithological character, organic remains, and geographic position clearly, but while he very clearly distinguished it from the St. Joseph (=Trenton limestone) and the Mackinaw (Dundee-Monroe=Helderberg in its original broad sense) limestones, he did not separate it from the shaly beds immediately above and below, which are indeed far from conspicuous in the outcrop. If we use the term Manitoulin, these limits may then be set to suit our convenience so long as the local equivalents of the Guelph and Lockport are not excluded.

As the Trenton marks the first, so the main mass of the Niagara (Schuchert's Louisville) marks the second, Paleozoic period of "epicontinental seas" of large transgression over the continent. The fact that Niagara is found in Limestone Mountain on Keweenaw Point, near Hazel Station of the Mineral Range Railroad, makes it

highly probable that all of Michigan at least was covered, and the freedom from land detritus makes it probable that the submergence was widespread, and that whatever land existed was low, and erosion mainly chemical. Elaborate subdivisions have never been made or mapped of the outcrops in the Upper Peninsula. Well-records, however, show toward the center facies that we may parallel with the New York Clinton, Rochester (Niagaran) shale, the Lockport limestone, and the Guelph dolomite, and besides this at least one fairly persistent sandy and water-bearing horizon, the Hillsboro sandstone.

17. *Clinton.* 0–130 feet.—It seems to have been well into Clinton time before that part of the state where now is the Clinton outcrop was submerged. While all writers recognize that the Clinton facies exists in the Upper Peninsula, Rominger does not consider it worth dividing, and none have tried to map it separately. A. Winchell makes it but 3 feet thick. On Manitoulin Island there may be 31 feet. Hall gives, p. 154, Sturgeon Bay, this section:

	5	light-gray Niagaran with *P. oblongus*	10
Possibly Clinton	4	thin calcareous and siliceous beds 6–10	25
	3	shaly and mixed beds Cytherina 15	
Possibly Medina	2	heavy-bedded greenish-calcareous and argillaceous limestone with chert nodules	6
	1	soft, brittle, greenish	20

The Cheboygan well shows some 60 feet which may be placed here.

In the southeastern part of the state nearer New York the Clinton is more surely identifiable.

The Port Rowan, Canada, well shows 75 feet under the Rochester.

Argillaceous dolomite seems to be the dominant rock. Water and gas are often struck in it under the Rochester shale. At South Bend there are argillaceous dolomites 1,180–1,300 feet. At Dowagiac a brownish-red carbonaceous limestone at the bottom (1,760 feet) may represent it. At Kalamazoo is an interesting section suggesting a land surface near 2,230 feet.

18. *Rochester shale.*—Above the Clinton a shale is generally identifiable in the records; whether it is the Rochester shale or at times part of the Clinton may be a question. Though persistent it is never very thick—usually 30 to 20 feet.

The Kalamazoo section of which there are samples is very interesting (but there is always the possibility of misplaced samples), and may mean that this part of the state was out of water at intervals up to the Louisville or Guelph epoch and that *after* the Clinton there was a minor re-emergence, as at the time of the Richmond Medina beds. The succession is the same, limestone, shale, and red beds, only on a smaller scale. It is also worth noting that the shale is "red" in the Carmen well; Petrolia, also "red rock" occurs just above this slate at South Rockwood (1,285–95 feet deep) near Detroit, and the Strasburg sample on top of the Clinton suggests emergence. Toward the end of the time of the Rochester shale then the shoreline probably passed through Kalamazoo. This is the more interesting because just southwest in Illinois[1] the Clinton is usually about as thick as in Michigan and is followed by a long break in sedimentation. Thus we may imagine that region emerging at the close of Clinton and staying so until after the Guelph, while Michigan did not emerge at Kalamazoo until after the Rochester shale and then at most during the lower part of the Lockport Guelph time only.

The peculiar feature of this time seems to be an oscillation or tilting, the Clinton extending more to the south, the Rochester and Niagara opening up to the north, and from the time of the Richmond Medina until after the Rochester shore-lines seem to have been in Michigan, with the continental shield fairly high. (Compare Schuchert, Pls. 64 to 66.)

19, 20. *Lockport and Guelph dolomites* (Manitoulin).—The Lockport and Guelph have different fossils but have never been separated paleontologically in Michigan. The upper limit against the Salina or Monroe is marked only in this way, that the Guelph is peculiarly hard and peculiarly white. One cannot absolutely depend upon the presence or absence of anhydrite as a dividing line. It is convenient at times to separate off the lower, less white and uniform part as Lockport (Louisville). The total thickness of the two at maximum seems fairly persistent and uniform, across the lower part of the state 350 to 270 feet. At the north part of the state it appears to be thicker. The well No. 2 St. Ignace gives just 600 feet, as a Cheboygan.

Extreme whiteness of the upper part, occasional sand grains

[1] Savage, *Illinois Survey, Bull. No. 8*, 108.

(1 per cent or 2 per cent, as though wind-blown) in the dolomites, and occasional beds of sandstone are characteristic all over the state.

It is exposed only in the Upper Peninsula. It forms the shore of Lake Michigan and Lake Huron in a continuous ridge which rises to the north almost at the dip of the beds, which is about 50 feet to the mile, from the lake level 580 feet A.T. in somewhat less than 10 miles to an elevation of about 800 feet A.T. Here and there it outcrops and very often the soil over it is thin.

While as a whole it is dolomitic, there are horizons, notably that of the Fiborn and Rex quarries, which run nearly pure calcium carbonate. They probably occur in the lower part beneath the Guelph.

The absence of sediment and the absence of iron and the fact that it is succeeded by a salt series suggests that the climate was not a very rainy one.

21. *Salina* (or Lower Monroe).—The term Monroe was introduced by me in 1893[1] to 1895, and as at first used without definition did not include all the beds down to the Niagara. In my later and more formal definition (Vol. V) I made it practically include all the Silurian above the Niagara, having found it impracticable to separate the Salina from the beds above. The difficulty still remains. The last salt bed is not always at the same horizon.

According to Grabau, there should be a marked hiatus and disconformity between the Niagara and the next overlying beds in Monroe County. The thickening as we go north, which is rapid and very great, would then be practically by addition at the bottom of beds formed during this disconformity.[2] Now, comparing wells at Britton, Milan, Romulus, and Wyandotte we do find an increasing thickness, and five feet of rock salt at Milan seems to be almost directly above the Niagara, whereas in Wyandotte there are 275 feet of dolomites below the rock salt and above the white dolomite. The rock salt at Milan is 717 to 722 feet below the base of the Sylvania, and *may* be continuous with a bed of 790 to 900 feet below it at Wyandotte, 1,080–1,190 or 1,235 feet. Again, as we go north the salt beds seem to occur higher up. Gypsum (anhydrite) certainly occurs

[1] *Report* for 1891–92, 66.

[2] *Bull. G.S.A.*, XIX, 554. Compare also Schuchert, *op. cit.*, Pl. 68.

above the Sylvania, and it is not very easy, though it may be possible, to separate off a part of the Monroe as Salina. The thicknesses given by Grabau for the Monroe below the Sylvania add up 500 feet. Salt occurs below the Sylvania usually within 450 feet. To the southeast on the Cincinnati anticlinal the salt disappears.

It is difficult to draw the upper line of the Salina in cases where no salt exists, and that is the excuse for considering the Salina as perhaps Lower Monroe. We have only lithological grounds to identify it with the New York Salina, and it is altogether unlikely that the top can be drawn consistently on such grounds. One can go only 400 feet below the Sylvania sandstone if present and then take the top of the nearest salt or gypsum bed. This gives fairly consistent results.

In the southwest part of the state, where no rock salt occurs, and all the Dundee and Niagara together do not amount to the Upper Monroe alone on the east side of the state, there was perhaps more elevation and more exposure to erosion.[1] The samples from 1,490 feet to 1,730 feet at Kalamazoo represent the Upper and Middle Ontarian and are dolomites with more or less anhydrite and quartz and *some red clay* at 1,650 feet.

Now if here was, part of the time, shore for land southwest, we should expect to find still less deposition at Dowagiac. I am inclined, therefore, now to raise the Niagara at Dowagiac even more than I did over Wright in Vol. V, to wit, up to 1,100 or 1,135 feet, taking in all the light limestones. The Dowagiac Monroe would then be only 100 feet (1,000–1,100) dolomite with 10 to 30 per cent anhydrite and quartz. If so, then the Niagara would come in the white limestone at the base of the Niles well and the Monroe between 625 and 985.

The outcrops near Milwaukee—the Waubakee dolomite of Alden, Lower Helderberg of earlier writers—are probably higher than Salina. At Ludington and Manistee, however, rock salt was struck, but apparently there is but one layer.

There is some question about a Ludington well put down by J. S. Stearns, with samples suggesting the absence of the Dundee there, and the presence of the Salina. But this agrees with Schuchert's Plate 75, and as we find over across the lake at Milwaukee

[1] Schuchert, *op. cit.*, Pl. 69.

the Traverse and Monroe (Milwaukee and Waubakee of Alden) represented, and not the Dundee or Corniferous, it is more natural to suppose the Dundee absent here also. The irregular red and rusty character of the Dundee samples at Manistee and the way it varies in the wells also suggests a deposit near shore frequently interrupted by disconformities.

Of the Frankfort well no samples have been kept, but I am told that the wells were put down deep enough to have reached the Niagara (1,800–2,200 feet) without striking rock salt and without reaching a very strong brine. So that it is likely that this was just outside the Salina sea like Milwaukee, while Ludington and Manistee were just inside.

St. Ignace and Cheboygan wells showed the New York Salina red and blue shale facies. We have therefore good reason to believe that at the close of the Niagara or Guelph the sea-level fell so that all of the southeastern portion of Michigan was above it. This begins the emergence between the Silurian and Devonian. If the salt deposits were laid down as a non-oceanic Caspian sea, we may suppose red shales like those of St. Ignace were deltas of a stream that fed it, and that the inland sea extended to the New York Salina where were other deltas from Appalachian streams. The bottom of the Salina sea should, however, have been below sea-level, like the Dead Sea at present, for we find just after Sylvania time, and at the beginning of the Devonian, incursions of ocean water and animals. Now, the top of the Niagara below this is not less than 1,200 feet at Wyandotte, and below the top of the Salina 700 or 800 feet. If then the top of the Niagara at Wyandotte was above sea-level after the Guelph, either the continent was raised something like a thousand feet, or there was warping of the crust during Salina. There was warping of the crust during the Upper Monroe, and since, but not, I think, enough to alter the fact that Lower Michigan has been permanently a basin. Any such emergence of the continent should have left traces in the sediments derived therefrom, sandstone or red shales derived from residual clays. No such beds are known to me. The Salina appears to me rather the result of but slight emergence, which grew more marked but irregular during the time of formation of the top of the Monroe.

As shown by various records, the Cincinnati anticlinal had formed and was out of water and divided the Salina sea[1] into two basins, connected perhaps by a channel through Canada between Goderich and Petrolia, north of Wallaceburg and Port Rowan, the one the New York basin, the other the Michigan.

The earlier salt beds appear to be heavier. A great many records report salt coming directly on top of "lime." Now this does not mean much, for without samples and careful observation one cannot discriminate limestone, dolomite, and anhydrite (anhydrous sulphate of lime). In many cases where samples have been saved, under the salt comes anhydrite and a good part of that which is reported as lime is really anhydrite. But in some it appears as if salt really did lie directly on dolomite. An explanation is suggested in my report for 1908, dependent on a supply of alkali water replacing the base calcium by sodium, making sodium chloride more likely to precipitate but retarding precipitation of calcium sulphate.

22. *Lower Monroe.* Bass Islands Series. 365–500 feet.—This is a series of dolomites with beds of oölite like those around Great Salt Lake, as Sherzer has shown. The cessation of salt-making may simply show that the climate had so changed that there was enough of a supply of water to keep the more soluble chlorides from forming. Or there may have been some light crustal shifting opening an outlet. There is in Michigan no sign of structural break between this and the Salina.

Grabau subdivided as follows, provisionally:[2]

d. Raisin River dolomite, zone of *Whitfieldella prosseri* with oölite zones	200 ft.
c. Put-in-Bay dolomite, zone of *Goniophora dubia; Leperditia* also....	100 ft.+
b. Tymochtee beds? (Winchell Ohio)............................	100 ft.±
Relations unknown; quite likely equivalent to some other division, shaly and thin-bedded	
a. Greenfield dolomites, Northern Ohio..........................	100 ft.±

The fullest lithological descriptions are given in the Monroe County report by Sherzer, VII, 46–100. Fossil lists are given by Grabau, *Bull. G.S.A.*, XIX, 545–49.

Oölite and sandy dolomites and dolomites with anhydrite which is primary, acicular or gashed dolomites in which the hollows were,

[1] Schuchert, Pl. 70, somewhat modified.

[2] *Bull. G.S.A.*, XIX, 554.

as Kraus has shown for Monroe County, probably filled by (strontium sulphate) celestite, are characteristic rocks both in Monroe County and in the Upper Peninsula. A series of wells at intervals of but a few miles at most have penetrated this series from the Ohio line to Port Huron. It outcrops and is exposed again near St. Ignace and Mackinaw City and the islands north of Beaver Island. It probably touches the Wisconsin shore near Milwaukee, and is reached by a series of deeper wells along the western side of the state. A list of locations will be found in the report for 1908.

As the total thickness from the base of the Sylvania down to the salt shown in numerous sections runs only from 337 to 400 feet at the outside, Grabau's estimates of the thickness of the subdivisions cannot be added. It is very often impossible to make lithological subdivisions. A bed of sandrock often occurs under the main Sylvania sandrock a short way. The Waubakee dolomite fossils in Wisconsin most suggest the list of the Raisin River and Put-in-Bay beds, and I think there is reason to believe this series more widespread and persistent than the series above or below. The salt series below certainly does not extend so far either to the south or to the north. To the southeast down in Ohio, where the Sylvania sandstone is very thin and the overlying beds between that and the Devonian limestones easily overlooked, this lower Monroe is still persistent. The fossils reported from Milwaukee and from the Upper Peninsula by Rominger[1] are Lower Monroe rather than Upper Monroe forms.

Finally as we trace the beds from the thinner "Helderberg" or Monroe sections of Indiana toward the thicker sections, between Algonac and Alpena, the addition seems to be of beds above and below to a nucleus of Lower Monroe which remains fairly uniform in thickness. But there is this difference as we trace the section north along the Lake Michigan shore from that which happens as we go east toward the Cincinnati anticlinal. In the former case the Traverse (Hamilton) thickens, but very little is seen of the Dundee beneath—between it and the Monroe—in fact, there does not appear to be much added to the Monroe itself. The explanation would seem to be that for a good part of the marked erosion intervals (Waubakee or Helderberg) between Niagara and Monroe and again between the

[1] *Michigan Geol. Surv.*, I and III, 28.

Monroe and the Traverse (Milwaukee or Hamilton) the east or Michigan side of Lake Michigan was out of water and the Wisconsin post-Niagara uplift was fairly uniform from south to north. On the whole, the south seems to have been first to emerge (since there is more Niagara at the north and the seaward opening was to the north). The Salina sea was left to deposit salt. The recession or submergence during the Monroe may have been uniform. Whether the next emergence began sooner at north or at south one cannot tell since there is so decided an erosion unconformity.

A small percentage (1 to 5 per cent) of sand found in the Monroe dolomites may have been wind-blown from exposed beds of sand in Wisconsin. Passing northeast we find the Lower Monroe persistent. I am inclined to think, therefore, that the Michigan seas of Schuchert's Upper Siluric maps should open to the north much more.

At Port Huron the Lower Monroe is (1,215–1,555 feet) 340 feet and making a considerable jump to Goderich, Canada, we find between the limestone group and the salt 364 feet. This persistent thickness is an argument that between Monroe County and Goodrich was continuous deposition and that we have a complete section here. At Grand Lake in the Alpena Land Co.'s well, we find the limestone coming down somewhat farther and very thick. At Alpena the whole Monroe appears to be only about 713 feet, but there are discrepancies in the depth at which salt is said to occur at the different wells around Alpena that may be due to dislocations of the Monroe before the Traverse.

There seems to have been a pre-Traverse dip from Alpena north, enough to counterbalance the present Traverse dip the other way and in that direction was limestone and the open sea.

To the east then the submergence of the Monroe was longer, the emergence at the close delayed, and as we shall see, intermittent, and a land-mass formed to the south during the Upper Monroe.

23. *Sylvania sandstone.*—30 to 440 feet thick as sandstone, 170 feet as limestone. This, the Middle Monroe formation, is easily described. It has been found only along the flank of the Cincinnati anticlinal as a well-defined bed. It thins toward the outcrop where it is between 50 and 100 feet thick. It is thickest in a line through Milan, Ypsilanti, and Royal Oak. It probably skirts the Cincinnati

anticlinal rather narrowly, for it is relatively thin at Britton, Ann Arbor, Mount Clemens, absent at New Baltimore, though present at Port Lambton and Marine City, and absent at St. Clair, but present at Port Huron.

Grabau and Sherzer are inclined to consider it aeolian. But the way the grains of sand occur in the dolomite or limestone as in Port Lambton (and in a series of records like those at Marine City [Vol. V], we find it shading into the dolomites) its fairly regular variation in thickness, similar at similar situations[1] on the Cincinnati anticlinal, growing thicker to the line of thickness above mentioned, suggest that if they were wind-transported they were water deposited. Of course, near the outcrop it may be more aeolian. Lithologically it is a pure (99 per cent) quartz sand of the highest grade of glass sand as white as sugar. The nearest like it of recent sands that I have found is one from Florida. Its extreme freedom from iron is not characteristic of desert sands. On the other hand, it seems to have a characteristically fresher water (stronger in sulphates) than the beds below.

The disconformity with the beds below which Grabau mentions is not marked, though there are red sandy-looking beds at about that horizon in a few wells. The disconformity above is most marked and, as Grabau has pointed out, a new fauna appears of puzzling affinities. It seems that in many places during the whole time of the Lower Monroe and the Middle Devonian the American continent was out of water, and the disconformity marking this period of emergence is the well-defined and accepted line between the Silurian and Devonian. This applies to Milwaukee and western Michigan. But the great basin of Lower Michigan was not lifted altogether out of water. The warping which caused the emergence lifted up the Wisconsin land-mass and also the Cincinnati anticlinal, and the Sylvania sandstones were formed as emergent sandstones along a shore not altogether unlike those from Chicago around to New Buffalo today. It was partly aeolian, but there is reason to think that much of the wind-blown sand found its final resting-place under the water, building a sandy shelf out from the shore.

[1] Compare Dundee, 60 to 253; Morton Salt Co., 65 to 262; Solvay, 95 to 415; Wallaceburg, 100 to 1,100; Port Lambton, 50 to 1,250.

But the emergence this time was not a mere recession of the sea-level. There was an Appalachian warping and gentle folding extending clear to Michigan, for as Grabau has pointed out, not only is there a disconformity of the Sylvania and overlying beds, but both together were folded and eroded before the Upper Helderberg was laid down, both around Alpena and to the mouth. One result of this was to permit an incursion from somewhere (judging by the thickening of the limestones from north of Alpena) of the first Devonian-looking fossils known, as described by Grabau. He tells me the same things come from the Saskatchewan.

It seems clear, comparing the records of the various wells, that to the northwest the Sylvania is replaced by a series of limestones.

Take the large group of wells at Marine City reported in Vol. V. In all of them at about 1,000 to 1,100 feet down, and about 500 to 600 feet above the first salt, 300 feet or so above a well-marked gypsum bed (which may be really the most fitting place at which to draw the top of the Salina) we find from 60 to over 100 feet of sandstone, often calcareous and passing into a sandy limestone or arenaceous dolomite, like the top of the Lower Monroe Raisin River beds. The same horizon is plain in New Baltimore 940–1,275; St. Clair 1,050–1,270, and Port Huron. There can be hardly a doubt that this corresponds to the Goderich Group III of Hunt, and so presumably to the Sylvania and part of the Upper Monroe. As usual *passing from the outcrop the unconformities* seem less. In its limestone facies it is impossible so surely to assign a thickness, but it seems to be about 170 feet. How much of this should be attributed to a thickened base of the Upper Monroe is a matter for further research. The fairly uniform thickness for Middle and Upper Monroe from Lake St. Clair to Alpena suggests no appreciable disconformity in this region. So far as one can judge the Upper and Middle Monroe are absent on the west side of the state. Even around Mackinaw and at Cheboygan there are no indications of them known to me. They are not shown on any of Schuchert's maps. I am not so sure they should not be placed on Plate 72.

24. *Upper Monroe.* Detroit River Series (275 ft.).—This series seems to have been deposited in a long, narrow trough at the very end of the Silurian at a time when most of the continent was out of

the water and much progress had been made toward the evolution of the Devonian forms. Just as in New York higher and higher horizons of the Eo-Devonian rest to the west on the Salina and water lime, so in Michigan to the southeast and south higher and higher horizons of this formation rest on the Sylvania. It is also true that the Corniferous or Dundee rests on various members of this. The Corniferous (Onondaga) above is unquestioned Devonian. The Monroe below the Sylvania will, by general consent, be classed with the previous period. But the Sylvania has often been called Oriskany and the fossils of beds above are remarkably like Hamilton forms, while the very top of the Lucas dolomite has been generally taken to be below the Devonian.

If, with H. S. Williams, we place the base of the Devonian at the Oriskany and class the Lower Helderberg beneath as Silurian (Ontarian) as used to be common (compare the 1892 edition of LeConte with the latest) we can then surely place the whole Monroe with the Silurian as I did. Canadian writers have generally grouped the Sylvania as Oriskany.

But beneath the Oriskany comes the Lower Helderberg series of New York 300–400 feet[1] and Pennsylvania 600 feet, and in Europe stages E and F, and the relation of these to the faunas is a complex problem of paleogeography. After the Salina (all up) was there a see-saw—first the Michigan trough down (Upper Monroe), then up, and the New York Helderberg down? This is the view accepted by Grabau. Or is it possible that at the time of the Sylvania the Michigan basin was so separated from that of New York that the two could have separate faunal developments at the same time, the New York receiving precursors of the Corniferous, Michigan of the Hamilton, while somewhere around there lingered relics of the Silurian faunas which re-established themselves when the old anhydrite- and dolomite-forming conditions returned in Michigan? This would imply that on Schuchert's Plate 72 a long sound of Upper Monroe should extend, opening to the north.

On the whole, the greater break as well as the most widespread, and therefore the one best fitted to mark the beginning of the Devonian, seems to be that above the Detroit River series. For there

[1] Schuchert, *Bull. G.S.A.*, XI (1900), 270; XX.

appears to be not merely a disconformity as between the Detroit River and the Salina but an actual unconformity, so that the Detroit River beds were folded before the Dundee and Traverse were laid down. Such a folding is indicated by the fact that while at Alpena there is[1] a dip of the surface beds 42 feet to the mile to the southwest this does not seem to be the case for the lower beds of the Monroe. The salt is as deep to the north. Again, along the St. Clair River in the Devonian there is an anticlinal near Port Huron where the oil wells are in the Traverse (Hamilton). But the Monroe beds do not follow this fold The salt runs more nearly on a level. Again, around Detroit in Wayne and Monroe counties, Grabau has described how the Dundee of the Devonian lies on various beds of the Monroe. For the present, therefore, it will be well to keep the line between Devonian and Silurian as heretofore and as Grabau wishes, remembering that with the line so placed, a very Devonian-appearing fauna already existed during the time of the Detroit River beds, and that, as in New York, between the Helderberg and the Oriskany[2] there is an unconformity and a more marked one prior to the Cobleskill Rondout, so it is with the Detroit River series, which from a structural point of view is closely allied to the Helderberg.

At the salt shaft, and near by, the subdivisions are, according to Grabau and Sherzer:

146		
	180	1. Lucas dolomite (with Cylindrohelium profundum) (200 feet+) with sulphur and gypsum.
326		
	9	*c.* Amherstburg dolomite (with Panenka canadensis) transition to Lucas—20 feet.
335		
	38	*d.* Anderdon limestone (with Idiostroma nattressi and a fauna like the Hamilton).
	40	50
373		
	47	*e.* Flint rock dolomite (with Syringopora cooperi).
	50	
420	150 feet+	
	Sylvania sandstone beneath.	

[1] *Report* for 1901, 67, and Pl. VII.

[2] See Grabau, *Geology and Paleontology of the Schoharie Valley*, 179; *New York State Museum, Bull. 92.*

It is next to impossible to trace these largely paleontological subdivisions in the wells, especially the difference between Amherstburg and Anderdon. But the tendency to a dolomite top, with sulphur reduced from gypsum and anhydrite, and limestone lower can be plainly followed.

Above the undoubted Lucas either as an extension of the base of the Dundee or as a still higher member of the Detroit River series (which it would be interesting to compare with the New York Helderberg) was an intercalation of limestone in the Lucas which did not reach as far as New Baltimore. By the time we get to Alpena, limestone occurs at various horizons. There is clearly a tendency to replacement of dolomite by limestone toward the north in the direction probably of the open sea. The Michigan Monroe seems to have been, like the Black Sea and Caspian, turned northside south.

At the close of the Monroe the state was so elevated that slight folds which occurred at the same time could be planed off, and the underlying formation in numerous places from Mackinaw to Monroe County, made into a dolomite conglomerate, calcirudite. So far as we know it remained above water during the opening stages of the Devonian Helderbergian. There is distinct reason to believe that *this* uplift was not a mere rise and fall of the sea strand produced perhaps by disturbances thousands of miles away like the earlier changes in Niagara time, but a tilting by which the west was more elevated than the east and a certain amount of folding took place. The Limestone Mountain fold on Keweenaw Point may have taken place this early. The Sylvania uplift seems to have been decidedly most at the south, opening up and depressing the land at the north. By the close of the Amherstburg the effect of a new uplift made itself felt in cutting off the northward connections and the conditions for formation of dolomite and anhydrite were re-established and with them the Silurian fauna. The same disturbance that cut Michigan off once more may have opened up New York to the Helderbergian, so that while the Coeymans and Port Ewen beds were forming in New York, 300 or 400 feet in all, Michigan was mainly out of water, and not until the Schoharie (Hall in Foster and Whitney, II, 225), did deposition that has been recognized by its fossils begin in Michigan.

DEVONIAN

25. *Dundee limestone.* 200 to 253 feet.—This formation—the Corniferous or Onondaga nearly—is full of fossils which have been described by Hall, Winchell, Rominger, Schuchert, Grabau, and others.[1] On the east side of the state between the blue and black shales that may represent the Bell or Marcellus and the first dolomite, which seems to be generally the top of the Silurian (of course, there may be a puzzling dolomite conglomerate at times) the formation can be traced persistently. It is very uniformly a high-grade limestone with only a small percentage of magnesia, not infrequently over 98 per cent $CaCo_3$, light colored, or brown with oily matter, containing a water relatively high in sulphates, relatively weak and strong in H_2S, and generally hard. It is sometimes, not always, cherty or "corniferous." Beginning with a thickness of an even 100 feet in the southeast corner of the state, it thickens slowly to Port Huron. Going west and north it at first thickens until it gets its full thickness of about 250 feet, and then begins to thin, as I now believe.

For instance, the Niles well on p. 280 of the report for 1903 may be interpreted as having only 12 feet of Dundee and then entering the Monroe, and that in Vol. V as (the Oriskany being at 540 feet) having but 40 feet, and all these wells in the southwest corner as striking through from some part of the Traverse corresponding to the Alpena limestone into the Monroe, the Dundee being omitted, agreeing with Schuchert's map, Plate 75.

As we go up the Lake Michigan shore northward it is apparent that the Traverse expands to the thick 600-foot section found in its northern outcrop, while the Dundee does not increase so much. The top thirty feet and other places are sometimes quite sandy and often cherty. It is not often sandy on the dividing line between it and the Monroe.

Throughout my work in Vol. V and the annual reports I have considered all the Dundee as a limestone and this has given consistent results. Four miles east of Mackinaw City, in a section where I thought I found the Dundee directly overlying magnesian limestones of the Monroe, Grabau found in the top layers of the magnesian beds a

[1] *Annual Report* for 1901, and *Bull. G.S.A.*, XVII (1901), 719.

typical Schoharie fauna, agreeing with Hall's determinations on Mackinac Island 50 years earlier. We must then grant the occurrence of magnesian beds near the base of the Dundee. It would be strange if overlaying a magnesian formation the base were not magnesian. The paleontological and structural dividing line may be a few feet beneath the lithologic line which I have had to use.

26. *Traverse* (Hamilton and Marcellus, Erian of Clarke and Schuchert, Delaware[1] of Ohio). 600 feet.—As this group is much thicker and better exposed in the north end of the state and its very existence along the south line of the state has been doubted, we begin our description from the north where it outcrops on Grand and Little Traverse Bays, and thence is frequently exposed around to Alpena and Thunder Bay, and is nearly uniform in thickness (600 feet with a basal shale, Bell shale, 80 feet, which corresponds to the Marcellus and is persistent throughout the state).

Grabau gives:

Chert beds..............	45–50	Naples goniatite fauna at top
Petoskey limestone........	360	Stromatopora and buff magnesian
Acervularia beds..........	110	Bryozoa beds
Bell shales..............	80	
	600	

When we get to Port Huron, nearer the Cincinnati arch, it seems to have shrunk to 330 feet or so. Thence down to the Ohio line it tends to shrink especially toward the axis of the arch. But the *marked black or blue shale base persists.* Hence there is reason to suspect that the loss is mainly by removal of the top. This would imply that our early Traverse is Schuchert's late Hamilton, Plate 76. There is a fairly persistent division to which the drillers apply customary names.

Cooper's 2. Petoskey limestone. The "top lime" 85± (sometimes pyritic at its top).

Cooper's 3. The "top soap rock" 150±.

Acervularia beds. "Middle lime" 4–15. Never thick, but persistent, the Encrinal limestone?

Bell shales? "Bottom soap rock" 65. Darker than the other.

[1] Sandusky has been discarded.

There is good reason to suppose that during *late* Traverse there was some emergence, while the line between Dundee and Traverse does not appear to be marked by a notable unconformity in Michigan. We find also in New York the closest affiliation in deposition between Onondaga and Marcellus. The supposed unconformity at the top and maximum depression at the base of the Traverse is in harmony with the description by the Wisconsin Survey (ii, 397) of the beds there as early Hamilton.

27. *Antrim shales.* (Senecan, Genesee ?, Portage and Chemung of New York, Ohio) Huron, Chagrin, Cleveland, and Bedford. 480 to 140+ feet.—There is good reason in the thinning of the formation and in the irregularity and reddening of the top to believe in an elevation south of Michigan toward the close of the Traverse (Hamilton). But in Iowa, too, the Upper Devonian is said to be unconformable on the Middle. At the base of the Antrim shales on Thunder Bay, Grabau found the Naples goniatite fauna which would imply, perhaps, that the Antrim black shales though lithologically like the Genesee were really somewhat later, and the Genesee missing.

This horizon is struck very widely. The full thickness is not less than 340 feet. In order to get consistent results and thickness one must recognize that the transition to the Berea Grit is gradual and a great thickness of Berea Grit or strata ascribed thereto is at the expense of the Antrim. The Antrim consists mainly of shales, black and bituminous at the bottom, then blue, and at top, where it passes into the Berea Grit, or the horizon thereof, red or interstratified with sandstones and gritty.

To put the base of the Carboniferous at the base of the Bedford we should have to split the Antrim in a very impracticable way, though we could readily enough follow Ulrich's suggestion and place it lower. It is noteworthy that just as the Sylvania is confined to the east side of the basin along the Cincinnati anticlinal, so is the Berea Grit, and when the Berea Grit does not appear, then the upper strata of the Antrim have a red facies like the Bedford of Ohio, or the Richmond top to the very similar Lorraine. This red facies is, it seems to me, very likely due to exposure to the weather. Where the Berea Grit is *well* developed it is, I believe, never found. It,

therefore, may indicate the uplift generally taken to mark the close of the Devonian and beginning of Carboniferous. The upper part of the Antrim is blue rather than black and frequently there are beds of sand and grit. There is generally at least 100 feet of the bottom black shale, but since the blue and black shales alternate at times, records may or may not show the Cleveland Chagrin and Huron as one solid black shale, or may overlook the Cleveland and count everything down to the Huron as blue shale.

MISSISSIPPIAN

28. *Berea Grit* (or sandstone[1]). 273 feet.—This is an Ohio formation and has never been seen at the surface in Michigan, but may be traced very well along the flanks of the Cincinnati anticlinal, from near Adrian north. Westward it seems soon to disappear and to be spotty in occurrence. Eastward it may well have once been continuous with its Ohio outcrops. Continuous past Ann Arbor and Pontiac and Birmingham, Romeo, Utica, and Berville to the southeast corner of Sanilac County it may be followed around the Thumb in wells put down to tap its brine to Bay City. From Bay City it may be traced north to Harrisville, near which it comes to the under surface of the drift. It thickens gradually from about 40 feet until it is thickest near its western margin (over 300 feet). Then it disappears suddenly. The brine is exceptionally salt, even near the surface, and unusually free from sulphates.

The sandstone is generally fine grained, micaceous, and overlain by a black shale (the Berea or Sunbury shale).

Now, if we take the Alma, Bay City, and Caseville wells and figure from the top of the Marshall as a datum we shall have the form of a deposit formed along a shore facing east and running nearly north and south through the center of Michigan (compare Schuchert's Pl. 78). It is also true that it is coarser where it is thicker and not so pure—more of a fine-grained grindstone to the east.

This points to a marked line between Carboniferous and Devonian. We have something like the same question that arises as to the red Richmond shales mentioned above, but there is a marked difference in that above the Berea Grit we do not pass into limestone like the

[1] Compare Oneonta Chemung and Catskill.

Clinton limestones, but back into black shales, like the base of the Antrim, the Berea, or Sunbury shale.

I am inclined to believe there was originally less sulphate in the brine and that would point to a less arid climate,[1] and with that the black shales and greater abundance of mud are in agreement. At any rate the Berea Grit seems to mark an episode apart from any *great* climatic change.

29. *Coldwater shale.* Part of old Waverly; Sunbury or Berea shale, plus Cuyahoga (which includes Buena Vista), plus Raccoon and part of Black Hand, perhaps; Orangeville and Sharpville? 1,000 feet.—The next series lithologically corresponds to the New York Portage and Chemung and is one largely of shales, which generally make valleys in the bed-rock surface and in a state so heavily drift laden as Michigan are rarely exposed. In Ohio there are two or three distinctions clearly made. The thickest, most carefully studied, and best exposed section is that of Huron County,[2] as follows:

Blue and sandy shales of Willow River and Secs. 2 and 3, Huron Township	172	
Black Hand of Ohio? in part		
Light House Point conglomerate, Herrick's I, Large fauna	4	176
Directly under should come the Raccoon, Herrick's Waverly shale fauna.		
Blue shales with carbonates of iron of Port Hope, Harbor Beach, White Rock to Forestville, with *Chonetes scitulus*, cf. pulchella, common throughout	720	896
Black Sunbury shale with *Lingula melie* and *Oroiculoidra newberryi* in Ohio	103	999
practically an even		1,000 feet

The black shale base is very persistent when the Berea Grit comes beneath, and continues as at Alma and Grayling, even beyond its limits and is presumably the equivalent of the Sunbury or Berea black shale of Ohio. Like that it is a persistent and widespread horizon whose thickness is generally only 25 to 55 feet, averaging about 40. It is clear that in well records there must be some uncertainty as to whether we are dealing with the red Bedford or the red

[1] See analyses in Clarke's data of geochemistry.

[2] Vol. VII, *Geol. Surv. of Mich.*, Part 2, pp. 18–27, 247–52, Pl. I.

top of the Sunbury in wells where the Berea Grit itself is absent. In the extreme western part of the state, as at Dowagiac and Constantine[1] (one well only) less than 20 feet of red shale has to do duty for Bedford to Sunbury, and the Antrim beneath is thin. I think the red shale is the weathered top of the lower formation. It is conceivable that the Berea Grit once extended farther and has been eroded away. On the whole, however, it seems more likely that while the whole period Bedford to Sunbury was one of elevation, there were two times when the shore-line advanced farthest east—one just before the Berea Grit, one just after the Sunbury shale, correlative to the Buena Vista flags.

There has been a question as to whether it would be better to cut the Berea or Sunbury shale off from the Coldwater. But it was included in the original definition of Coldwater and has been recognized in Michigan only lithologically. It would seem best for the present to keep the term Coldwater as originally introduced to cover the interval from Berea Grit to Marshall, and use the Ohio terms Sunbury and Cuyahoga, Buena Vista and Raccoon for fitting subdivisions when possible.

Brines and sandstones seem to appear not really at the Berea Grit level but somewhat above, but correlations are largely guess work, as all of these sandstones are readily overlooked by drillers on the one hand, and none of them are thick, and sandy, salty streaks are liable to occur at various levels without question. Hard streaks are also liable to occur which are largely bands of iron carbonate, or they may be huge round kidneys, such as are known to exist.

The outcrops of the Coldwater were described by the first Geological Survey, Hubbard, and others, by Winchell in a long series of papers,[2] and by Rominger,[3] who calls it and the Marshall, the Waverly Group. It covers a considerable area.

On the western side of the state the Upper Coldwater (or possibly the Lower Marshall) about 300 feet below the top or 700 feet above the bottom becomes distinctly more of a limestone. At least that is one way to interpret the records.

[1] *Annual Report* for 1903, 281, 282.

[2] *Biennial Report*, 1860. See also Weeks in *Bull. 191* on Marshall.

[3] Vol. III, Part I, chap. viii, 67, 75.

Alma has sandstone, black shale, and limestone between 1,575 and 1,740 feet, i.e., 560 feet below the top of the Marshall, corresponding to Bay City 1,630 feet in the well of Vol. V (Atlantic Mill), 750 feet in the South Bay City well. This we may strongly suspect includes the upper part of the Coldwater down to Herrick's conglomerate 1, the Black Hand and Raccoon.

In the Charlotte well from 570–680 feet is sandrock, from 680–1,150 appearing to be shaly limestone, if the samples are representative. There are 350 feet below down to the Berea horizon. So at Jackson is a salty rock at 660 which, in Vol. V, I took to be the Napoleon, but I am quite sure that I was mistaken. This would seem to be an appearance of the Michigan series, or rather a Kinderhook facies and an incursion of the western Carboniferous during the Coldwater. It looks as though at about this time (that of the Coldwater and Marshall) the eastern side went up, the western side down, and that corresponds with what is known of the continent in a large way.[1]

The abundance of goniatites in the sandy beach-like beds of the Lower Marshall suggests that they were open to the western ocean, and we should expect an even more Kinderhook facies in the Upper Coldwater and Lower Marshall of the western part of the state. Unfortunately there is not the slightest chance of outcrops of this calcareous Lower Marshall or Upper Coldwater, but possibly some fragments of the fauna might be identified in the drift back of Ludington.

The Coldwater is an emergent formation and gradually passes into the sandier facies of the Lower Marshall; where to draw the line will be discussed in connection with the Marshall. The Coldwater appears to be nearly as thick even if more calcareous to the west, the total for Lower Marshall and Coldwater being always a little over 1,000 feet.

30. *Marshall sandstone* (Raccoon possibly, Black Hand and Logan of Ohio in part).—This formation was extensively studied by Professor A. Winchell who, in distinction from earlier writers, recognized the Carboniferous type of its fauna, when he first introduced the term (report for 1860). He made a heavy sandstone which he called the Napoleon the base of the Carboniferous, and called the

[1] Compare Schuchert, Pls. 78 and 79.

beds beneath the Marshall, the top of the Devonian corresponding to Chemung. Later[1] his investigations led him to include this Marshall with the Carboniferous, and then he also united the Napoleon andstone with it as Upper Marshall, and finally concluded apparently that it was not worth separating but only a lentil. The whole matter is discussed in full in the Huron County report. The Marshall is evidently a case of emergence on the east first, micaceous sandstones becoming more and more abundant, and bands of carbonate of iron and fossils, while blue shales still persist in layers. At a number of places white sandstones occur and thin beds of what I have called peanut conglomerate, white quartz pebbles with heavy cement of carbonate largely of iron, which weathers brown and gives the color effect of peanut candy. The transition from Coldwater is gradual, and it is not easy to fix the line consistently. In fact there are some paleontological reasons for believing that the whole southwestern Marshall may be older than the Huron County.

The Huron County section is fullest, as follows:

Napoleon (Upper Marshall) sandstone	300	300
Lower Marshall (Original Marshall)		
Hardwood Point shales and sandy flags, fossiliferous, "typical Marshall" fauna	85	385
Point Austin sandstone	23	408
Sandy shale	68	476
Point Aux Barques sandstone	18	494
Shales and flags with Romingerines Julia	41	535
Grindstones with bands of peanut conglomerate and broken goniatite shells	25	560

The southern Marshall is thinner and since it is an emergent formation it is easy to assume that this part of the formation emerged sooner and was more eroded, and not so soon covered. The series that came after the emergence should also be less complete and as a matter of fact the Michigan series here lacks gypsum and seems otherwise less complete.

But may it not be that not only did emergence but the tendency toward emergence indicated by the sandy facies begin sooner? There is faunal indication of this.

[1] See references in Weeks, *Bull. 191, U.S.G.S.*, 260. But add also *Am. Jour. Sci.*, XXXIII, 352–56, and *Proc. Acad. Nat. Sci.*, XIV, 405–30.

A simple and natural explanation of faunal relations would be that the Marshall emergence took place earlier to the southwest than to the northeast. This does not agree with Schuchert's maps. If so, the question at once arises, must we not reverse our definition of the Lower Marshall, bringing it down to include the Raccoon shales and their equivalent in Huron County, down to Port Hope nearly, adding 200 feet to the Huron County section, and making the Marshall there over 760 feet thick? This may be the future solution of the question. Cooper leans to it. But we should be as sure as possible before making changes. So we must ask what indications are there of a land mass in this direction? Also are there any indications of a shortened geological column to the top of the Marshall in this direction?

There is a little thinning as compared with the Huron County section, but not enough, and no shrinkage as compared with the center of the basin. We have besides to allow for a dropping-out of Berea beds and for the unusual thickness of the Huron County Upper Marshall as given in the column which seems *very* local.

The limestone character of the western Coldwater is rather against its earlier emergence, as well as the relatively wide spread of the western Kinderhook.

There is an alternative hypothesis (supposing the paleontological facts to remain established) and that is to suppose that the Paleoneilo fauna of the Raccoon shales were immigrants northward that reached Ohio earlier but did not reach Michigan until later—until after the beginning of the Marshall. This seems to me the more likely because the fauna most like that of the southern Michigan Marshall that we find in Huron County is way up in the Lower Marshall at Flat Rock Point.

31. *Michigan series, Lower Grand Rapids.* Logan possibly absent in Ohio? (380—generally about 200).—The Marshall is Kinderhook of the Illinois reports. Following the Marshall there was an emergence and an interval of erosion without deposition of some time around the edges of the basin, but perhaps none near the center, for the series there is of greater thickness and its deposits of gypsum attest its cut-off character. In the Mount Pleasant well it is 358 feet

thick—the fullest of any in the state. There is always a gypsum or anhydrite bed near the middle of the formation, and with this is associated dark-colored dolomites and dark-blue shales. Sandstones are thin and irregular and in some cases there are dark limestones toward the base. These dark, impure limestones, are quite different from the Bayport limestone. The section around the margin if at all full is something like 200 feet, but from Tuscola County south to the Assyria are a lot of wells in which it is hard to recognize this or the Bayport at all. Occasionally, as around Byron, very salt water near the surface may indicate outliers of it. The water from the formation is salty and "bitter," full of calcium and magnesium sulphate and in that respect very different from the Marshall immediately underlying. The absence of the Michigan series from the southeastern part of the state seems to be due not wholly to erosion at top, but to uplift of the bottom, the emergence of the Marshall having progressed so far that this part of the state like the corresponding part of Ohio was out of water.

The date of this emergence during which the Lower Michigan was forming in the center of the basin is pretty definitely fixed on paleogeographic grounds as that of the Upper Augusts or Osage.[1] The Michigan series seems to have continued forming until a depression to the west opened connection with the wide ocean at the time of the Maxville of Ohio, Upper St. Louis or Kaskaskia and Chester of the Mississippi Valley. The section seems to be continuous without disconformity to the overlying limestone, which I have called Upper Grand Rapids, since both sets of beds were well exposed near Grand Rapids and seem in many ways bound together. The Lower Grand Rapids must then include the Lower St. Louis and probably the Keokuk and perhaps in the center strata representing part of the Burlington, the time Kinderhook-St. Louis including an era of emergency in which all of Michigan but a central sea was out of water.

The dark and sometimes even black slates and the blue and dark, impure dolomites give the formation a more muddy look than the Salina, while the general association of dolomite and gypsum is like that of the Salina, and one is inclined to believe that some land waste and rain erosion were still going on, though local conditions favored

[1] The emergence between Schuchert's Mississippi and Tennessee.

concentration and after all chemical erosion and deposit were much more important in the Grand Rapids than at any time since the Traverse.

32. *Maxville or Bayport limestone, Upper Grand Rapids, Upper St. Louis, Middle Kaskaskia.* (50 to 235 feet usually eroded).—This formation marks the culmination of a transgression.[1] Generally it is only 50 to 75 feet thick or less, and seems to be much eroded away by a heavy erosion and uplift that took place after its formation. But in the Mount Pleasant well 235 feet may belong here.

Light, hard limestones, bluish with chert and white sandstones are characteristic. It is the typical old subcarboniferous limestone. Faunally (with Allorisma, Lithostrotion canadense, etc.) it is also closely allied with the Upper St. Louis, the middle of the Kaskaskia, and the Ohio Maxville—an epoch of maximum ocean extent at this time. I do not know any good reason for not calling it Maxville.[2] Owing to the heavy subsequent erosion there is no telling how far it may have extended, but it certainly extended into Huron and Arenac counties and thence west. It also extended south of Jackson, and may once have gone into Ohio continuously.

However, in a region from Tuscola County south around Durand, Morrice, and Howell, there seems to be an area where it does not now occur and perhaps never occurred. An anticlinal uplift either prevented its formation or caused it to be eroded away. From Jackson to Grand Rapids past Bellevue and Assyria, however, there are frequent signs of its presence though the coal measures are laid upon it with a very marked unconformity.

On the whole, the climate was not one that favored the formation of shales, but limestone, chert, and clean white sandstone rather, and as the continent was sinking the rivers tended to aggrade and leave their mud before reaching the sea.

At the close of the Bayport formation the state was quite likely lifted entirely above water for quite a while,[3] since wells in the center of the basin as near to each other as Alma, Mt. Pleasant, and Midland show very different sections, and the Parma conglomerate base of

[1] Schuchert's Tennessee which he makes early Chester, Pl. 81.

[2] See *Michigan Miner*, December, 1906; *U.S.G.S. Water-Supply Papers*, 182–83.

[3] Schuchert, Pl. 82.

the coal measures appears sometimes at one level, sometimes at another. The Bayport is apparently entirely gone at Alma.

This, then, would be the line between the Mississippian and Pennsylvanian, in this state the strongest disconformity since that at the base of the Devonian, and the first time that there is any evidence that the whole of the state was above water.

PENNSYLVANIAN

33. *Parma conglomerate; Pottsville* (170 feet; basal member).—The recurrence of deposits in Michigan is marked by a bed of conglomerate. The pebbles are not always present, to be sure and are rather small and very white, about like split peas, and the mass of the formation is sandstone. The name is taken from a point on the margin of the basin which is very likely contemporary with shales, etc., in the center. As a term, then, it is, like the Potsdam, not to be taken as of definite age but as the underlying basemental and shoreward facies of the Saginaw formation. As a very persistent horizon easily recognized by the presence of pebbles, which are rare in the Michigan column, and as an economically important water bearer it deserves a place in the column. Compared with the Marshall brine beneath, it has less of the earthy chlorides, more of the sulphates.

The wells of the Saginaw Plate Glass Works yielded a set of samples which show the characteristic Parma and the strata above and below.

34. *Saginaw formation. Upper Pottsville* (400).—This is the coal-bearing series of Michigan. All the other formations seem actually to dip and occur deeper at the center than at the margin of the basin. Mr. Barnes, chief driller of the Consolidated Coal Co., thinks that for this, too, the marginal coal seams, at Sebewaing and Jackson, correspond to the deepest seam at the middle. I am hardly inclined to think it. Their chemical character is more like upper seams and the fauna and flora of the upper seams at the center and at the margin seem similar. The series is a succession of white shales (so-called fire clays) or sandstones, black shales (called slate) and coal, and blue shales, with occasional thin bands of black band ore (siderite), and nodules of the same containing zinc blende and iron

pyrites, and very rarely limestones with marine fossils.[1] More commonly, but still rarely, in the black shales a *Lingula carbonaria* or *mytiloides*, and at Grand Ledge a little pelecypod like Anthracosia occurs, and this Lingula seems to mark a definite horizon, that of the Upper Verne, the two Verne coals often occurring close together and sometimes having a limestone between.

The fauna and flora indicate Upper Pottsville (Beaver or Kanawha) near Mercer (compare the Kanawha, Black Flint, Mercer limestone and Stockton coal), and is also near the top of the Saginaw formation. How much lower the base may possibly go we have no means of knowing. But there is reason to believe that there was not continuous deposition even in the center of the basin, and the Upper Pottsville is over 1,200 feet in West Virginia.

As a whole, the formation is composed of beds of rather rapidly varying thickness and character. This is true also of the coal seams. In one mine they will rise and fall 20 feet and more, pinch out or pass into black shale. A curious feature is a local persistence of facies. That is, in one township there will be a great deal of sandstone at many levels, at another there will be much shale at all levels, in one region many of the coals will be prominent, in another none. Finding a good upper coal is by no means a sign that the coals below will be extra thin.

This points to a certain persistence of geographic condition. That is, if a big sand dune or sand bar occurred in a point flanked by a peat swamp on one side and muddy clay-depositing waters on the other, while it extended more or less widely and shifted a little from time to time, yet it tended to remain in the same general region and even built up as the general level of the water rose. We can see that this might be so by watching the effect of rises and falls in the level of the Great Lakes. A rise of 7 feet may not seriously shift the location of a swamp and the barrier beach that cuts it off from the main lake.

The writer made a list of some seven coal horizons, to which Cooper has added seven more. When we consider that the whole 14 occur within 400 feet, most of them too thin to work, and that one seam may vary 20 feet or so in elevation in a couple of hundred feet,

[1] Vol. III, Part 2, 42, 43, 96, 203; *Report* for 1907, 19; *Report* for 1905, 185, 188.

but little stress can be laid on any such series. The Verne bunch are, however, at a fossiliferous (Mercer) horizon often quite close together, showing as a 7- to 8-foot wall with partings (compare the Stockton coal) and it is curious that White gives 13 horizons in the West Virginia Upper Pottsville.

I have an idea that they give a drowned-river-valley effect to the southeast side of the basin, the longest axes of the coal running northwesterly in a very irregular way, but the general shore-line trending southwesterly from Huron County, something like the Carolina shore south of Hatteras turned around.

POSSIBLY PERMO-CARBONIFEROUS ?

35. *Woodville sandstone.* 110 feet (Conemaugh).—Winchell separated off above the coal measures a sandstone 79 feet thick he called the Woodville. It was named from an exposure at Woodville near Jackson.

Now, at Maple Rapids, St. Johns, Ionia, and Gladwin,[1] we find a brown or reddish sandstone. This is not a normal color for a coal-measure sandstone. It may be that this reddening is an effect of weather, but I think not, and we may as well call it Woodville until we know the Woodville does not represent it. Ionia would be a much better name. The Woodville exposure is not red but buff. Still it is weathered, friable, and over 40 feet thick. From the way these red beds occur in some wells but not in others near by in the Saginaw Valley we may be pretty sure that they are unconformable to the series below. I suspect, therefore, that it is not Allegheny but at earliest Conemaugh, some land-formed deposit of the late Carboniferous (Pennsylvanian) or early Permian. No fossils are known. The red formations seem to be more abundant in the western part of the state but that part is heavily covered with drift, and the redness may be a purely secondary Mesozoic oxidation.

During the rest of the Paleozoic,[2] the Mesozoic and the Tertiary Michigan was, so far as known, out of water, though there is reason to believe that at the time of the Cretaceous the sea reached nearly or quite to it, and it was nearly worn down to base level. At some time everything from Niagara to Keweenawan around Lake Superior was

[1] Vol. III,,Part 2, 158, 159, 164, 166, 195, 196, 197.

[2] Schuchert, Pl. 84.

leveled off, and even the harder felsites and granites did not rise more than four or five hundred feet above the general level. As we find fragments of Upper Cretaceous not far off in Minnesota on the Mesabi Range we are inclined to put the culmination of this period of leveling at that time.[1]

On the other hand, deeply incised valleys and caves in limestones suggest a period of high level in the Tertiary between that time and the ice age. Some time someone may find in the prosecution of the limestone quarrying, around Fiborn or Alpena or Monroe in the caves upon which one comes, vestiges of Tertiary cave life. I do not know of any yet.

PLEISTOCENE AND RECENT DEPOSITS. 1,110–0 FEET

Michigan is so near the center of the latest glaciation and that was geologically so recent, the effects of ice blocking the St. Lawrence valley having lingered so far as one can judge until within a few thousand years, that it does not seem sensible to divide the Glacial and Pleistocene from the present. Mammoth and mastodon bones are found within a few inches of the surface and where forest clad, the topographic forms left by the ice are almost as sharp as when left, with much less alteration than 50 years of farming make. However, beds of peat 30 or 40 feet thick, of boglime, lacustrine, and alluvial clays 14 feet thick and perhaps more have accumulated and formations like the delta of the St. Clair flats, Tawas Point. So far as we can estimate none of these post-Glacial deposits need have taken over 10,000 years.

The greatest thickness of the Glacial-Pleistocene deposits we may estimate to be 1,110 feet near the north line of Osceola County, southeast of Cadillac. But the greatest thickness actually measured is in the deep wells near by on the Lake Michigan shore at Manistee and Ludington, where the rock surface is below sea-level, but they can hardly be separated systematically in a geological column. Both in the character of the pebbles, however, and in other ways, a transportation from the northwest as well as the northeast is plainly indicated, and at least one period between the two during which red lake clays were in some places laid down.[2]

[1] Schuchert, Pls. 94–95.

[2] *Report* for 1906, Russell on "Surface Geology," 43, 73; Rominger, I, Part III, 17.

CRETACEOUS–EOCENE CONTACT
TOMBIGBEE RIVER, ALABAMA

EUGENE ALLEN SMITH
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The Selma chalk, which is so beautifully exposed at Demopolis on the Tombigbee River, grades upward into a more argillaceous material a few miles below the town. A fine exposure of this variety is at Barton's Bluff on the left bank of the river, about ten miles below Demopolis. For a distance of a mile or two above Barton's and at the bluff itself, there are scores of faults of a few feet displacement. Some of these are of the nature of step faults, others, especially as the bluff is neared, bring the white chalk of the Demopolis variety in wedge-shaped blocks up into the dark-colored clayey material characteristic of the bluff as a whole. In places the strata show a very considerable amount of flexure in addition to the faulting. Fig. 1 is given in illustration.

Below Barton's for some distance the banks of the river show very few good sections until Moscow Landing is reached. Here the bent, fractured, and faulted beds of the Cretaceous are overlain unconformably by the lowermost (Midway) beds of the Eocene of this section.

The main mass of the Cretaceous, forming the base of the section exposed at Moscow, is a light-colored argillaceous limestone not unlike the Selma chalk of the Demopolis type. The dark-colored clayey beds of Barton's Bluff are not shown here. This limestone is a somewhat massive rock with stratification lines very obscure, but near the top of the formation there is a thin layer of phosphatized shell casts which may easily be followed along the bluff and by which the attitude of the strata may clearly be made out. The Eocene beds which form the upper fifteen or twenty feet of this section are of material very similar to the Cretaceous limestone below. Along a good part of the bluff this Eocene limestone lies in immediate contact with the Cretaceous, and when this is the case the uncon-

formity is very little apparent, since the phosphatized shell-cast layer of the Cretaceous, above alluded to, runs practically parallel to the stratification lines of the Midway with a gently undulating dip down stream. Near the base of the Eocene there is a thin layer of shells of a small oyster (*O. pulaskensis*, Harris) which very clearly indicates the attitude of the Eocene strata, as the layer of phosphatized shell casts does that of the Cretaceous. At the extreme right and left of Fig. 2, this approximate conformity is shown. The dark line immediately above the contact is made by the layer of oyster shells.

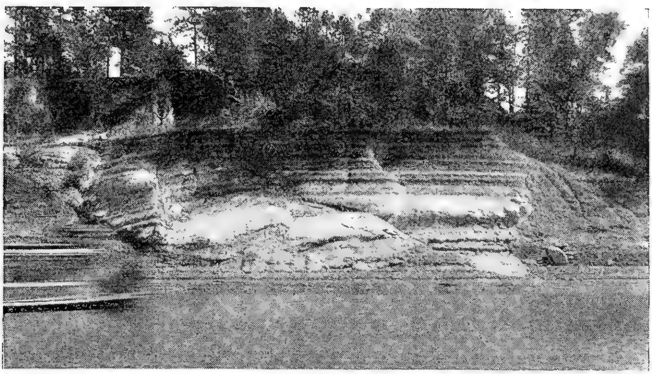


FIG. 1.—Flexures and faults in Cretaceous strata at Barton's Bluff, Tombigbee River, ten miles below Demopolis, Ala.

At intervals, however, especially in the up-stream part of the bluff, there are hollows in the Cretaceous limestone, formed partly by erosion and partly by flexure, in which are plano-convex lens-shaped masses, twenty to forty feet in length, made up (*a*) of a sort of conglomerate of Cretaceous shells, mainly exogyras and gryphœas, in a chalky argillaceous limestone matrix, in all some three or four feet in thickness, and above this, (*b*) a glauconitic sandstone, strongly crossbedded and filled with Cretaceous shells, some of them very much water-worn. These two fillings may clearly be seen in the lens at the left of Fig. 2. In the lens at the right of the figure the sandstone is very prominent, but the underlying shell conglomerate does not show so well. A remarkable thing about these sandstone lenses is the manner in which the strata are flexed and their edges

Fig. 2.—Moscow Landing, Tombigbee River, Ala. Contact of Cretaceous and Eocene, the latter resting directly on the beveled edges of the sandstone lenses, and where these are not present, upon the Cretaceous limestone, often in apparent conformity. Immediately above the line of Cretaceous-Eocene contact another line may be traced the whole length of the bluff, made by a thin layer of the shells of *Ostrea Pulaskensis*. The central part of this section is much disturbed by faulting which involves both Cretaceous and Eocene. Three sandstone lenses are here seen occupying erosion or plication hollows in the Cretaceous limestone.

beveled off at the contact with the Eocene. This is particularly well shown in the lens at the right of Fig. 2.

Overlying the Eocene limestone, lower down the river than either of the views shown in the figures, are black shaly clays, the Sucarnochee clays of the Alabama Survey, exposed in great thickness at Black Bluff a few miles below Moscow Landing.

Near the upper end of the Moscow Bluff both Cretaceous and Eocene beds are faulted, the displacement being generally only a

FIG. 3.—Bluff near Moscow Landing, Tombigbee River, Ala., showing two of the sandstone lenses in erosion hollows in Cretaceous limestone. Both Cretaceous and Eocene strata are faulted. The strata which directly overlie the beveled edges of the sandstone lenses are Eocene.

few feet, as may be seen in Fig. 3, the beds immediately above the beveled-off sandstone lenses being Eocene. Along many of these fault planes sheets of calcite, one or two inches in thickness, have developed, with one surface after the manner of a slickenside.

When this bluff was first visited by D. W. Langdon and the writer in 1886, the small oyster was thought to be *O. vomer*, and the whole section, with the exception of the black clays at the lower end of the bluff, was referred to the Cretaceous; but on a visit to the locality

made in 1908 by a party of state geologists and others on a trip down the river from Tuscaloosa to Jackson in Clarke County, several specimens of *Enclimatoceras Ulrichi* were found in the upper limestone bed, and the small oyster was recognized as *O. Pulaskensis*, thus establishing the horizon as that of the Midway.

It has been suggested that the glauconitic sandstone is a basal Eocene bed, but its local character and the unconformity between it and the Midway everywhere would militate against this view. The unconformity, in places, between it and the Cretaceous below, is, however, equally pronounced.

There are many things about these sandstone lenses which are not easily understood. Thus, to all appearance these beds after their deposition have been tilted and their edges beveled by erosion, and this in one or two cases without any perceptible disturbance of the Cretaceous limestone upon which they rest. This is shown by the fact that the bed of phosphatic shell casts, which presumably marks a stratification plane in this limestone, in approximately horizontal position, in some cases, maintains this attitude to the very edge of the erosion hollow containing the shell conglomerate and sandstone; while in other cases this phosphatic shell bed bends down below these hollows, as though they were produced by plication and as though the stratification of the Cretaceous limestone were conformable to that of the shell conglomerate and sandstone.

THE INFLUENCE OF THE EARTH'S ROTATION UPON THE LATERAL EROSION OF STREAMS[1]

HENRY M. EAKIN

Introduction

It is a well-known fact that rotation of the earth upon its axis sets up a tendency in bodies in motion upon its surface to deviate from a straight course, in the northern hemisphere to the right, and in the southern, to the left. Different writers[2] have considered the possible results of this tendency in modifying stream erosion, but in general little importance has been attached to it, striking results of its operation not being commonly observed.

The most satisfactory analysis of the problem is Gilbert's, in which he notes certain processes involved in stream erosion not usually considered and endeavors to make a quantitative measurement of the effect of the deflective force acting relative to them. He points out that centrifugal force is developed on the curves of meandering streams. Velocity being a factor of this force, so-called "threads" of higher velocity will tend more strongly toward the outer bank on curves. The rotational deflective force depending also upon velocity will affect the "threads" of higher velocity more strongly. The effect of this stronger tendency of the swifter threads one way or the other he expresses as a "selective influence," whereby they migrate nearer one bank or the other, displacing threads of lower velocity and accelerating lateral erosion. In the northern hemisphere the rotational deflective force acts in conjunction with centrifugal force on right curves, and on left curves in opposition to it. Consequently the locus of maximum velocity would be shifted toward the outer bank more strongly on right curves than on left curves, the cross-

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] Dunker, *Zeitsch. für die gesammten Naturwissenschaften* (1875), 463; Klockmann, *Jahrb. Preuss. Geol. Landesamt* (1882); Geikie, *Textbook of Geol.*, I, 23; Chamberlin and Salisbury, *Geology*, I, 184; Jefferson, *Bull. Geol. Soc. Am.*, XVII, 333–50; Gilbert, *Am. Jour. Sci.*, 3d ser., XXVII, 427.

section profiles of the stream would be correspondingly modified, and a difference in lateral erosion would ensue. The efficiency of rotation to produce appreciable results is advocated only in "connection with and as an adjunct to lateral wear by means of curvature."

In certain Alaska streams the writer has noted a strong predominance of erosion on the right bank, shown by asymmetry in the position of the river with respect to the flood plain, the distribution of bluffs on the right and left limits, and in the distribution of bars and islands relative to cut banks. In the case of the Yukon, in the last 600 miles of its course the flood plain, 20 to 50 miles wide, is almost entirely on the left-hand side. It flows close to the right valley wall almost the entire distance, often with steep, fresh-cut bluffs in bed-rock. The left bank is commonly alluvium, bed-rock being encountered only once in this distance. And in the single instance mentioned, opposite the mouth of the Melozi River, a large delta has been built out by the tributary stream, literally crowding the larger river over to the left valley wall. In this part the Yukon is essentially without meanders, being characterized by long straight reaches and gentle curves.

Also of great significance in the case of the Yukon is the behavior of driftwood and floating débris. Such material is almost entirely absent from the left bank, but is plentiful on the right. And in flood time, when the current is well supplied with such material, its distribution on the stream surface is most striking. It is confined almost entirely to the right half, and often to a much smaller space along the right bank. Eddies along the right limit are often crowded with drift; along the left never, so far as observed. At Nulato, where the river is about a mile wide, the natives get a large supply of wood by catching drift logs, and they seldom have to go more than 300 feet from the right bank to secure them.

The problems presented by these conditions have stimulated study, which has led to an analysis of the processes of river erosion considerably different from that described above. In the following pages, after a simple review of the principles to which the deflective force is due, it is intended to emphasize its greater strength in higher latitudes, to show that its expression in unbalanced lateral erosion is least in streams where meanders are in process of development and

greatest in streams with straight courses—that the force is opposed to the development of meanders and in high latitudes may fully account for the conditions described above.

The Deflecting Force of the Earth's Rotation

For a brief elementary review of the principles which give rise to this deflecting force, we may imagine the earth perfectly smooth and friction eliminated. This force has two modes of origin, one being active when the relative motion is in an east-and-west direction, the other when the relative motion is north and south. In case the relative motion is not in any true direction, both modes are active at once, and the deflecting force has two components arising in different ways, but acting similarly.

To get these components distinctly in mind we may consider them separately. (For convenience the following abbreviations may be used: F_g=force of gravity, F_c=centrifugal force, F_d=deflective force of the earth's rotation.)

Component of Deflecting Force Arising from East-and-West Relative Motion

An object upon the earth's surface and at rest with respect to it has a certain gyratory velocity equal to that of the earth's surface at the same latitude. This gyratory motion gives rise to a centrifugal force, acting in a plane normal to the axis of rotation. Owing to the nature of the ellipticity of the earth, a gradient is furnished at every point whereby a part of the force of gravity is caused to oppose and exactly counterbalance this centrifugal force, and the object would have no tendency to move either toward or away from the equator.

However, if the object had an easterly motion with respect to the earth's surface, it is readily seen that the centrifugal force would be increased and the ellipticity of the earth's surface would no longer be sufficient to cause its counteraction by gravity. The resultant force would furnish a component acting along the earth's surface toward the equator to the right in the northern hemisphere and to the left in the southern. Again, if the object had a westerly motion relative to the earth's surface, the centrifugal force would be decreased

and the ellipticity of the earth, being more than a match for it, the object would tend to slide down the gradient toward the poles, to the right in the northern hemisphere, with respect to the direction of its relative motion, and in the southern hemisphere to the left. These principles do not require that the object move directly east or west, but operate so long as there is an easterly or westerly component in its relative motion.

Component of F_d Arising from North-and-South Relative Motion

Another component of the deflecting force of the earth's rotation arises when the relative motion is in a northerly or southerly direction. Suppose an object at rest with respect to the earth's surface at a latitude of parallel A be acted upon by a force causing it to move to a higher latitude of parallel B. At parallel A the object had a certain gyratory velocity corresponding with a point in the circle A. Being drawn toward the center of gyration in moving to a smaller circle, this gyratory velocity is accelerated according to the law of conservation of angular momentum. And since the gyratory velocity of a point in Circle B is less than that of a point in Circle A, and the gyratory velocity of the object is greater than that of a point in Circle A, the object has come to have a gyratory velocity very different from the earth's surface at the same latitude.

This difference would give the object a relative motion in an easterly direction, to the right in the northern hemisphere and in the southern hemisphere to the left.

If the object were at rest at Circle B and were caused to move to Circle A, the reverse of the above case would be true. The actual gyratory velocity of the object would be decreased according to the same law, and the earth's surface would have a higher velocity at Circle A than at Circle B. The object would have gained a negative component of velocity in a westerly direction with respect to the earth's surface, and, as before, the deviation would be to the right in the northern hemisphere and to the left in the southern. In either case should the object have, at the start, a relative motion, the same principles would be effective.

Effect of F_d on Objects Moving in Fixed Courses

Obviously, if the object were not free to move as these forces would direct it, but were constrained to move in a fixed channel, the deflecting force would cause it to press against the side of the channel. Now, if the channel were along a meridian, only one component of the deflecting force would be active, or, if along a parallel, the other alone. But if the channel were in any other direction, the movement of the object would have both a north-and-south and an east-and-west component of motion, and both components of the deflecting force would operate proportionately to the components of relative motion from which they arise. And since, according to Ferrel,[1] the amount of the deflecting force arising from an east-and-west relative motion is exactly equal to the amount due to a north-and-south relative motion under similar conditions, it follows that at any given latitude for the same rate of relative motion, the deflecting force is constant, regardless of the direction of the relative motion.

Measurement of F_d

The amount of this deflecting force varies with the rate of relative motion and the latitude.

Using Ferrel's formula,[2] $\frac{F_d}{g_m}=\frac{2NS \sin L}{9.806}$ (N=gyratory velocity of the earth in terms of the radius; S=rate of relative motion; sin L=sin. of the angle of lat.; g=accelerative force of gravity), and adopting arbitrarily a definite rate of relative motion of 2 meters per second, or $4\frac{1}{2}$ miles per hour, the expression of the deflecting force in terms of the force of gravity for each fifth degree of latitude is given in column 2 of Table I.

Taking the amount of the deflecting force at the fifth degree of latitude as a unit of measurement, the amount active at each fifth degree of latitude is given in round numbers in the third column of Table I.

For comparison with the more familiar effect of F_c as developed on curves, radii of curvature have been computed which would

[1] Ferrel, *Popular Treatise on the Winds*, 42–88.

[2] Ferrel, *loc. cit.*

generate F_c, approximately equivalent in effectiveness to the deflective force operative under the same conditions at each fifth degree of latitude. These figures are given in column 4, Table I. The same velocity is assumed as in the former calculations. (In these computations a symmetrical arrangement of velocities with respect

TABLE I

Lat.	$\frac{F_d}{F_g}$	Ratio	R
5.........	.00000260	1	65.00
10.........	.00000516	1.9	33.0
15.........	.00000770	2.9	22.0
20.........	.00001018	3.9	16.0
25.........	.00001258	4.8	13.0
30.........	.00001488	5.7	11.0
35.........	.00001706	6.5	10.0
40.........	.00001912	7.3	8.6
45.........	.00002104	8.0	8.0
50.........	.00002278	8.7	7.3
55.........	.00002438	9.3	6.8
60.........	.00002576	9.9	6.5
65.........	.00002696	10.3	6.2
70.........	.00002796	10.7	6.0
75.........	.00002874	11.0	5.8
80.........	.00002930	11.2	5.7
85.........	.00002962	11.3	5.66
90.........	.00002974	11.4	5.60

to a central maximum, decreasing directly with the distance from the center to zero at the margins, has been assumed. This introduces an error which gives a greater relative value to F_c and adds to the value of the radii computed. This error varies with the actual arrangement of velocities in the stream, but probably would never amount to more than a small percentage.)

Rôle of F_d among the Forces of Flow

In studying the movements of water in a normal river we have to do with three forces that are setting up and directing currents: F_g acting down the general stream gradient, causing the primary current, and F_c and F_d arising from this primary movement and acting always at right angles to the direction of flow, F_c always toward the outer bank on curves and F_d always to the right in the northern hemisphere, to which the study will be confined in the following pages.

Each particle in motion feeling a lateral impulse, whether from F_c or F_d, will tend to move in that direction. For simplicity, we may take the case of a stream acted upon by F_d only. The lateral impulse will be transmitted to the right, so that each particle will feel the combined impulse of all those to the left in strata of equal pressure. The tendency will be for all to move to the right until a lateral gradient is established that will furnish at each point an equal impulse in the opposite direction. In a stream with velocities in each stratum of equal pressure arranged symmetrically with respect to the center, this gradient would be a compound curve with a general inclination to the left (see *aa*, Fig. 1).

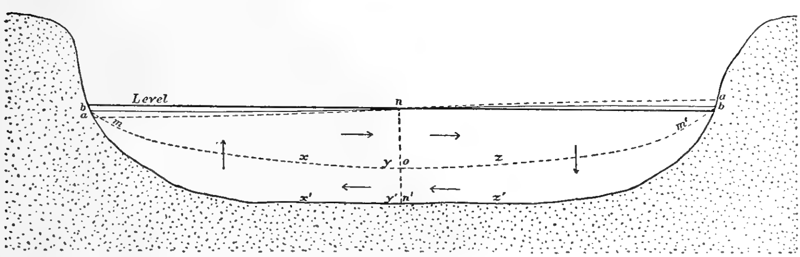


FIG. 1

But this potential gradient is never established. The velocities of the particles at x', y', z' (Fig. 1), being less than those at x, y, z, are unable to support the same lateral gradient, so that, before the potential lateral gradient for x, y, z, is established, some lesser gradient will cause a movement of x', y', z' to the left. This actual gradient would be constant for any set of conditions and would also be a compound curve (see *bb*, Fig. 1).

At some point between x and x', the force of F_d will just equal the opposing impulse from the actual lateral gradient. At this point no lateral movement will take place. Above it movement to the right will occur, below it, movement to the left. Between other points similarly related, like conditions will hold, giving a zone in which lateral movement is absent (*mm'*, Fig. 1).

Since the curve representing the potential gradient is stronger than that of the actual and the area of the cross-section of the stream

is practically constant, at some point the two must coincide, and no vertical movement will occur. And so, for each stratum of equal pressure we will have a zone (*nn′*, Fig. 1) without vertical movement. To the right all particles will have a downward component of motion, to the left, an upward component. At the point of intersection of *mm′* and *nn′* all impulses are balanced save F_g acting down the stream gradient.

The stream has, then, a central axis about which a sort of revolution takes place. Under the influence of either F_c or F_d or of both, the stream progresses with a boring movement.

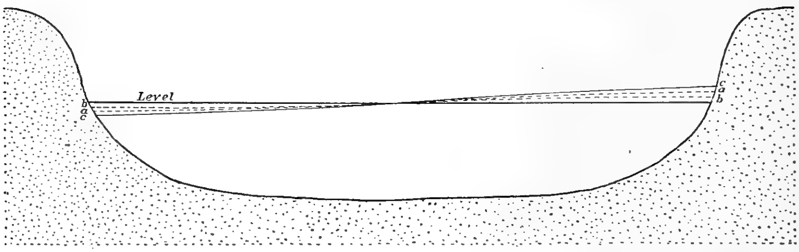


FIG. 2

Being the last factor that can be closely approximated, we may take the potential lateral gradient of the stratum of maximum velocities on the right and left curves of a meandering stream as a measure of the relative tendency of lateral erosion.

On the right curves F_c and F_d will combine. This condition is expressed graphically in Fig. 2, in which *aa′* represents the gradient arising from F_c, *bb′*, that from F_d, and *cc′*, the resultant.

The condition of left curves is illustrated in Fig. 3, *aa′* representing the potential gradient due to F_c, *bb′*, the potential gradient due to F_d with the inclination to the right, and *cc′*, the resultant potential gradient, being the mean.

Mathematically the potential lateral gradients on right and left curves may be computed and compared.

Using Ferrel's formulae for F_c and F_d and the data of Humphreys and Abbot on the Mississippi at Columbus, Ky., the potential lateral gradient would be 18 per cent stronger on the right curves. In this

case, however, the velocity data are taken from measurements on a straight reach of the river having a very symmetrical profile. The distribution of velocities being very different on curves, different relations would probably hold between the mean velocity and mean squared velocity, and the above ratio would be changed. The computation, the result of which is given above, involves less assumption than any other method of attacking the problem discovered and the figure, 18 per cent, may be safely considered of the same order of magnitude as that expressing the actual difference of potential lateral gradients on right-and-left curves in this case. The relation

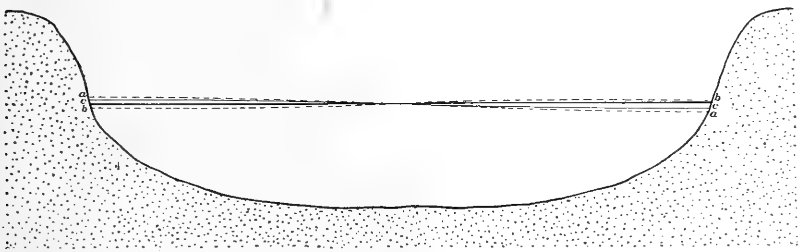


FIG. 3

between potential lateral gradient and consequent lateral erosion varies with other factors so that an attempt to compare the actual erosion on right-and-left curves would be idle. It is readily seen that, as the radius of curvature increases, the relative value of F_c decreases, until on straight reaches it becomes zero. On straight reaches, then, F_d is acting alone, and the tendency is 100 per cent to the right, its strength depending on the velocity of the stream and the latitude.

Boring Currents in a Meandering Stream

In a meandering stream the potential lateral gradient is reversed on each successive bend. The tendency is for all particles in motion to move toward the outer bank, establishing an actual lateral gradient corresponding to the potential. For a period, friction being low, the actual gradient will be high, since the momentum of the boring currents developed on the preceding curve must be checked and lateral inertia overcome before the boring currents normal to the

reversed gradient gain headway. But as such lateral currents are accelerated, friction increases. Friction in that part of the current moving in a positive direction or with the lateral force consumes part of the energy of the lateral impulse so that the actual gradient is lowered. Friction in the part of the current moving in the negative direction consumes part of the accelerative force of the actual gradient.

A condition of equilibrium is reached when the actual gradient becomes such that it is just maintained by the excess of lateral impulse over friction in the positive part of the current and whose accelerative force is balanced by friction in the negative part of the current. This adjustment is made by the shifting of the stratum of non-lateral movement which alters the relative proportions of the positive and negative parts of the current. The higher the actual gradient the larger will be the negative part of the current. As acceleration goes on and the actual gradient becomes less, that part of the current having a negative component of motion becomes more and more closely confined to the bottom of the channel and its efficiency in handling débris correspondingly increased. The condition of equilibrium would represent the maximum of efficiency. That such a condition is not represented in much of the course of a meandering stream is sure. That it is represented in any part is not certain.

Boring Currents in a Straight Stream

On straight reaches no reversal occurs. The condition of equilibrium between lateral forces and friction should be established. Therefore F_d, operating on straight reaches, should be immensely more effective in directing lateral erosion than an equivalent amount of lateral force operating in a meandering stream.

As pointed out by Hagen,[1] Herschel,[2] and others, the power of flowing water to erode its channel depends very largely upon the swirls, eddies, and such inner movements of particles among themselves. Such minor movements might well be called the teeth of the current, it being for the most part their action that wrests material from the bank or the bed of the stream and places it in proper relation to the current to be transported. These minor movements are due to friction between parts of the current, differing in velocity. Their

[1] Hagen, *Handbuch der Wasserboukunst*, Part II, Art. 21.

[2] Herschel, *Jour. Franklin Inst.*, 3d ser., LXXV, 401.

strength and effectiveness depend upon the amount of difference in velocity in a given distance.

The lateral shifting of the locus of maximum velocity and the downward deflection of the stronger upper currents adjacent to the outer bank on curves mark these points as loci of maximum erosion. But equally important in the development of meanders is the deposition of the débris resulting from the cut, normally on the inside of the next curve below the cut, and on the same side. Early in the development of a meander the lateral currents are weak. The débris-laden currents are not shifted far toward the center of the stream before the reversal occurs, their carrying power is changed, and deposition takes place. In more developed meanders the lateral currents being stronger, the loaded parts of the currents are shifted farther and carry their burden a greater distance. In development of meanders, then, the débris is deposited farther and farther from its source, but normally on the same side. When the meanders are strongly enough developed, the load should be shifted entirely across the channel and back again on subsequent curves, and in this may lie an important factor in controlling the width of meander belts.

If, however, in the case of a stream having a straight course, currents are set up by a force other than that due to curvature, the débris will be shifted constantly in the same direction. There will be no deposition below the cut on the same side, and consequently no deflection of the stream. The lateral currents, being constantly in one direction, will mark one side of the stream for dominant cut, and the other for maximum fill.

Whether due to F_c or F_d, the selective cut and fill due to the lateral currents introduce and maintain an asymmetry in the channel profile which, in turn, further modifies the distribution of mass and consequently of velocities in the stream cross-section. The result is to accentuate the selective cut and fill due directly to the lateral currents. The slightly increased depth on the side of the stream toward which the lateral force acts furnishes still another, though probably small, factor in favor of the same selective erosion.

If the foregoing principles are true, we have an adequate explanation of the peculiarities shown by the Yukon and other Alaska streams.

The Tanana River, the largest tributary of the Yukon, in the last 200 miles cuts bed-rock only on the right side and has almost all of its extensive flood plain on the left side. The lower Koyukuk has broad flats to the left and usually rock-cut banks on the right. Spurr notes a similar condition in the Kuskokwim, and Maddren in the Innoko. Though lacking the absolute data on which to base definite measurements of the effect of rotational deflection, the general knowledge of the streams mentioned above seems sufficient to establish the fact of its notable operation in high latitudes. That other causes may produce asymmetrical valleys is not denied. If a larger amount of rock débris is supplied by the tributaries on one side than on the other, the tendency is certainly to crowd the main stream to the opposite valley wall. The thawing of the bank most exposed to the sun would favor greater erosion in that direction. A tilting of the landmass would favor a widening of the meanders on the down-tilted side, but any moderate tilting would have but little direct effect on the lateral erosion of a stream. In affecting the carrying power of the tributaries, however, a notable shifting in the direction of the down-tilting should result.

However, these processes, singly or combined, cannot account for all the peculiarities observed in the Alaska streams and in the lower Yukon, the most striking instance of unbalanced erosion, there is no evidence of their operation at all.

Reasoning that, if such notable difference in lateral erosion should be effected in high latitudes, rivers in lower latitudes should show the result of the same influence to some lesser degree, the Missouri River was chosen for comparison. The Missouri has a well-developed flood plain, meanders broadly, and has been engaged in progressive de-gradation probably since late Pleistocene time. The summary results of all the factors directing its erosion during this period of time should be expressed in the present condition of the river and its valley.

The distribution of the flood plain with respect to the river was measured on the compiled Index Map of the Missouri River Commission, between Sioux City, Ia., and Kansas City, Mo. The results were:

Between the river and the left valley wall, 1,370 sq. miles.
Between the river and right valley wall, 312 sq. miles.

In the upper part of the river, from Fort Benton, Mont., to Sioux City, Ia., we still have what might be termed the first generation of meanders, that is, they are still in a developmental stage and swing first against one valley wall and then the other.

The form of these meanders, of such simple history, is significant. Those to the left of the mean axis of the stream are as a rule sharper than those to the right, the river is in contact with the right valley wall more often than with the left, and those reaches where the river is in contact with the right valley are longer generally than those where the contact is with the left valley wall. This latter characteristic becomes more and more notable down-stream.

In the reach from Fort Benton to Sioux City meanders have been cut off in five cases. Of these, four are on the left side of the stream and one on the right. However, in the case of the individual meander on the right, instead of receding from the loop, as is normal when cut off by differential migration, the river is at present encroaching upon it, making it very probable that the case represents domestic piracy rather than the former process. In each test stronger erosion on the right seems evident.

The influence of the earth's rotation, then, is to unbalance the lateral erosion of streams, in the northern hemisphere directing the stronger erosion on the right bank, and in the southern, on the left. The deflective force is much stronger in the higher latitudes. Its influence is felt by streams both with and without meandering courses and is most effective in streams with straight courses. Examination of streams in both high and mean latitudes reveals conditions of unbalanced lateral erosion that seem best interpreted as the result of rotational deflection.

GLACIAL LAKES OF PUGET SOUND

PRELIMINARY PAPER

J. HARLEN BRETZ

On the western margin of the North American continent an uninterrupted fjord coast extends from Cross Sound in the Alaskan panhandle southward to Puget Sound in the state of Washington. The topographic expression of the whole extent of coast line is glacial,[1] but the Strait of Juan de Fuca appears to separate this coast into (1) a region of predominant glacial erosion and (2) a region where glacial deposition much exceeded the erosion of the ice. Puget Sound is this latter region to a unit.

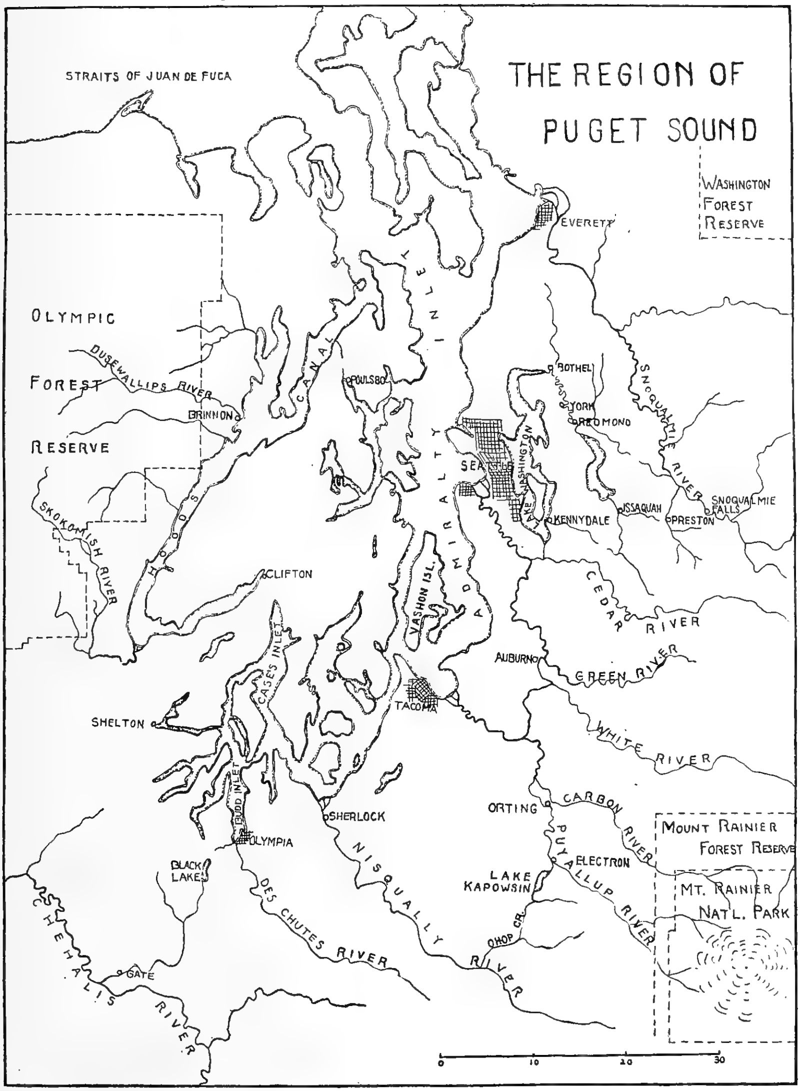
The complexly fingered arm of the sea known as Puget Sound lies in meridionally oriented troughs whose walls sometimes rise in sea cliffs 300 feet A.T. and whose maximum depths are approximately 1,000 feet below sea-level. To sea-level, at least, these fjord-like troughs are largely drift-walled. The larger stream valleys, lake valleys, and divides of the Puget Sound region are likewise fashioned in glacially transported material, and all share the roughly meridional orientation.

It is established that the ice of the last glaciation of Puget Sound was derived largely from snowfields to the north.[2] The axial lines of the grooved topography parallel the striae, and the ridges and valleys are at least veneered and often deeply covered by the youngest till of the region. The Vashon[3] ice which deposited that till sheet must have been related to the genesis of this peculiar and persistent topography in one of three ways: (1) the ice conformed closely to the ridges and grooves which were fashioned before its advent; (2) the last glaciation produced the present topography by erosion of an older and more nearly uniform drift surface; or (3) the Vashon

[1] G. K. Gilbert, "Glaciers and Glaciation," *Harriman Alaska Expedition.*

[2] Bailey Willis and G. O. Smith, "Tacoma Folio, No. 54," *U.S. Geological Survey.*

[3] Willis names the last glaciation of Puget Sound from Vashon Island, where its till is typically developed ("Tacoma Folio," *U.S. Geological Survey*).


THE REGION OF
PUGET SOUND
STRAITS OF JUAN DE FUCA
WASHINGTON
FOREST
RESERVE
EVERETT
OLYMPIC
FOREST
RESERVE
DUSEWALLIPS RIVER
BRINNON
SKOKOMISH RIVER
HOODS CANAL
POULSBO
ADMIRALTY INLET
BOTHEL
YORK
REDMOND
SNOQUALMIE RIVER
SEATTLE
LAKE WASHINGTON
KENNYDALE
ISSAQUAH
PRESTON
SNOQUALMIE FALLS
CLIFTON
VASHON ISL.
CEDAR RIVER
CASE'S INLET
AUBURN
GREEN RIVER
TACOMA
SHELTON
WHITE RIVER
BUDD INLET
SHERLOCK
ORTING
CARBON RIVER
MOUNT RAINIER
FOREST RESERVE
OLYMPIA
NISQUALLY RIVER
PUYALLUP RIVER
ELECTRON
BLACK LAKE
LAKE KAPOWSIN
MT. RAINIER
NAT'L. PARK
DES CHUTES RIVER
OHOP CR.
CHEHALIS RIVER
GATE
0
10
20
30

invasion modified an older drift topography to that now existing. As to which of the explanations is correct, this paper is not concerned. For present purposes it is sufficient to show that, with ablation of the Vashon ice sheet, the topography essentially as it now is was exposed.

The depression occupied by Puget Sound is inclosed on the west by the Olympic Mountains, on the south by a low gravel plain between the Sound and the Chehalis River, and on the east by the Cascade Mountains. At the maximum of Vashon glaciation, the ice sheet filled the entire depression, extending south of Olympia at the most southern tip of Puget Sound. Outwash at this maximum stage is largely responsible for the extensive gravel plain constituting the Chehalis-Sound divide.

When retreat of the front of the Vashon ice sheet began and exposure of the depression of Puget Sound progressed northward, water accumulated at the ice front to a depth sufficient to escape across the gravel plain southward to the Chehalis River. The meridional orientation of hills and valleys exposed by ice retreat, together with the fact that the ridges were higher than the outwash plain across which drainage escaped, caused the ponded water to accumulate in long arms and inlets quite like those of the Sound today. Troughs without opening southward and closed by ice at the north would contain independent water-bodies whose levels were controlled by the lowest place in their basin rims. Troughs with openings lower than the Chehalis-Sound divide would become part of a complexly branched lake, whose level was controlled by the lowest altitude of that divide.

How far north did the retreating fingered ice front serve to hold up the increasing glacial waters to the discharge-way across to the Chehalis River? Postulating an uncrevassed ice sheet of sufficient thickness, the dam should have been effective during retreat throughout the entire length of the Sound. Denying this postulate, subglacial drainage of the lake seaward (northward) might have occurred early in ice retreat, in the manner described by Russell for lakes in the Malaspina Glacier at the foot of the Chaix Hills.[1] Investigation

[1] I. C. Russell, "Second Expedition to Mount Saint Elias," *Thirteenth Annual Report, U.S. Geological Survey*, Part II. Suggested by Willis in personal communication to writer.

of the glacial features of Puget Sound has hardly gone far enough to justify definite conclusions on this question as yet. A brief description of the records of the principal glacial lakes of the region, as far as they have been studied, is given here, since such data alone can substantiate the preceding hypotheses and answer the question raised.

GLACIAL LAKES OF HOOD'S CANAL

The form of this remarkable body of sea water is that of a great hook, the main portion of which is 50 miles in length and about two miles in its notably constant width. The broad valley of the Skokomish River joins the southern tip of the Canal from the west in much the same fashion that the arm which makes the hook form joins from the east. The topographic disposition of the trough of Hood's Canal and the two tributary valleys is perfectly adapted to the production of a lake of glacial water in front of the ice during its retreat. The inclosing drift bluffs at the head of the Canal are about 350 feet high, and from this altitude a gravel plain slopes gently south toward Shelton. Two or three channels across it are known in part, and probably represent escape of water from the earliest and highest ponding at the head of the Canal. This early lake was held to the level of about 350 feet in the main trough and up the two north-trending arms, while the ice retreated northward. The enlarging water-body reached the head of the northeastern arm before any important change of level occurred. Near Clifton a pass was exposed to Case's Inlet southward, lower than the gravel plain to Shelton, and, with exposure, it became the discharge-way of the glacial lake of Hood's Canal. The very distinct channel here is 60 feet deep, the col in it lying at about 220 feet A.T. The operation of the Clifton outlet determined a new lake level, and may thus define the second stage of the glacial lake of Hood's Canal. Discharge from both the first and second stages was into the larger lake held back of the Chehalis-Sound divide.

The bluffs of Hood's Canal, followed northward, continue everywhere sufficiently high to have held the glacial waters up to the Clifton outlet for almost the entire length of the Canal. The ridge and trough arrangement of the topography is interrupted in the broadest part of the peninsula between Hood's Canal and Admiralty

Inlet by a group of high hills of igneous rock. North of them the prevailing meridional orientation again occurs, and in the southern portion of one such trough, Dogfish (Liberty) Bay lies today. This till trough continues north across the peninsula to Hood's Canal with a swamp col near midlength 120 feet A.T. Here then was a pass lower than the Clifton outlet, and with its exposure the level of the ponded glacial waters fell and the Clifton channel was abandoned.

The Poulsbo channel, the outlet from Hood's Canal to Dogfish Bay, has valley sides that rise to an altitude of 200 feet above the col. A definite stream floor fragment lies on the east side of the summit, at about 150 feet A.T.

At the mouth of the Dusewallips River which enters Hood's Canal from the Olympics, occurs a portion of an ancient delta of that stream, the seaward front rising quite steeply from marine water to an even crest of 120 feet. It lies on the north side of the valley mouth, the form and extent being well shown in 20-foot contours on chart 6,450 of the U.S. Coast and Geodetic Survey. Save for one post-glacial ravine, no break occurs in the plane surface which reaches back at least two miles with an almost imperceptible slope upstream. The surface of the plain is everywhere of sand and stream-rolled gravel. Obviously this delta correlates with the 120-foot level of the Poulsbo channel. The significance of the 120-foot level and of the 150-foot terrace in the Poulsbo channel will be discussed later.

GLACIAL LAKE OF PUYALLUP VALLEY

One of the larger meridional troughs of the region lies parallel to Admiralty Inlet on the east. It is occupied in its northern extent by Lake Washington and, retaining its character of a till trough, reaches as far southward as Orting. Originally an arm of the Sound, post-glacial alluviation has silted it up. The most southern break in the valley walls is at Tacoma, and the topographic conditions south of this are such that a local glacial lake must have existed in the valley early in the final retreat. This portion of the trough is properly termed the Puyallup Valley.

The only known record of the Puyallup glacial lake is its outlet valley. In this valley lie Lake Kapowsin and Ohop Creek. A col just south of Lake Kapowsin causes a small stream entering there

from the east to divide, one portion flowing north to the shallow linear lake and thence to the Puyallup River, the other reaching Ohop Creek and draining into the Nisqually River. The altitude of the col is 620 feet, above which the old valley bluffs rise 350 feet. It is probable that the deposits of this stream have raised the level of the Kapowsin outlet. The western margin of the Puyallup Valley northward toward Tacoma averages only 550 feet A.T. and Lake Puyallup must have early abandoned the Kapowsin outlet and found escape through spillways westward.

With discharge by either route, the waters of the lake were tributary to the larger lake held back of the Chehalis-Sound divide. When the ice dam failed to be effective, the Puyallup Valley became one of the group of flooded troughs constituting the major glacial lake of Puget Sound.

GLACIAL LAKES OF THE SAMMAMISH VALLEY

The Sammamish trough lies parallel to Lake Washington on the east. It has its inception ten miles north of Bothel and gradually deepens to its abrupt termination near Issaquah. The modern Lake Sammamish, seven miles long and 35 feet A.T., lies well to the south in the valley, a wooded swamp occupying the part north of the lake to Bothel and a creek draining the remaining length. The valley's southern portion is inclosed by three high rock hills, rising 1,500, 2,000, and about 2,500 feet A.T. Two low passes of preglacial origin cross the inter-hill areas. Beetling cliffs confine them in places.

East of Issaquah, altitude 90 feet, and on the northern flank of the largest of the three rock hills, is a considerable level area with an altitude of 425 feet. Coarse gravels and cobbles of glacial drift compose the surface, and are exposed in strata in several sections. Back from the margin of this deposit is a terrace 20 feet higher and with a still more extensive level surface continuing eastward. The face of the gravel deposit comprises the eastern wall of the Sammamish trough at Issaquah, and is dissected to a depth of about 300 feet by the stream which here enters from the east. Followed upstream, this creek is found, four miles out of Issaquah, to be wandering through a wide, flat-bottomed, swampy valley in which the stream appears incongru-

ously small and ineffective. The valley floor here is about 50 feet higher than the gravel deposit with which it doubtless correlates.

At Preston, this old floor suddenly ends at 540 feet A.T., with the valley at full width. A descent of about 100 feet occurs to Raging River which comes in from the southeast and turns north at this point. But the level of the valley floor at Preston is continued, in the form of terraces, up the Raging River for four or five miles to the point where the grade of the stream has brought it up to the level of the Preston Valley.

At the time that Raging River was discharging into the Sammamish depression, it seems probable that an ice tongue occupied the trough, and held back the river to the level of the deposit referred to above. This deposit, hardly to be considered as a delta, is the oldest record of glacial waters in the Sammamish Valley.

A glacial lake of limited extent must have succeeded the ice tongue in the southern portion of Sammamish Valley, and discharged southward through the rock-walled valleys noted, both of which are floored with coarse, rounded gravel. The lowest altitude at which this lake could have existed with these discharge-ways is about 315 feet.

A channel exists across the till ridge between lakes Sammamish and Washington at the north base of Newcastle Hill, the lowest of the three rock hills noted. It is floored with coarse gravels. Another channel a mile north of the one just noted contains Phantom and Larsen lakes, and is floored with swamp deposits. Both are about 300 feet A.T., and must have existed contemporaneously or nearly so with the southward escape.

A third abandoned channel across the till ridge between the two parallel valleys exists near York, or Willows, a few miles north of Redmond. The summit of the York channel is 160 feet A.T. and no perceptible slope exists in the swampy bottom to the west. This fact argues a similar level of ponded water in the Lake Washington valley. Lake Washington's surface today is 130 feet lower than the col.

Correlating with the York channel is the highest level of the Redmond delta, a heavy gravel deposit which lies a mile east of the town of Redmond. This delta occurs at the debouchure of a former chan-

nel of Snoqualmie River into the Sammamish Valley. It is a gravel plateau, one square mile in area, rising abruptly, along its western and northern margins, from the lake valley bottom. Its summit profile is made up of four levels, 120, 130, 140, and 160 feet A.T. Excavations on the lakeward face show the entire height of about 70 feet to be composed of stream gravels, and in at least one case to have foreset bed structure. The terraced surface clearly records dissection of higher levels in the development of lower ones, and proves their development in a lowering water-body.

The relation of the highest level of the Redmond delta to the York channel has been noted. For the remaining levels, 140, 130, and 120 feet A.T., the present outlet past Bothel must have served. The valley here is one of the few till troughs of Vashon or earlier date, whose orientation is other than meridional. It must have presented so low an escapeway on its exposure that it cannot account for the three lower levels of the Redmond delta. Their explanation must be sought elsewhere, and will be discussed under the following heading.

GLACIAL LAKE OF PUGET SOUND—LAKE RUSSELL

It is now time to examine the records of the master lake of Puget Sound, whose level was determined by the Chehalis-Sound divide, and which in turn controlled the descending levels of several, if not all, of the minor lakes of the region.

This lake began its existence when the withdrawal of the Vashon ice sheet first exposed surfaces lower than the great gravel outwash plains between the Sound and the Chehalis Valley. Across these plains all escaping water from the Vashon glacier must have flowed as long as the ice remained a dam at the north. As already noted, there is the possibility of escape of drainage northward through englacial or subglacial tunnels at a level lower than the Chehalis-Sound divide, before the clearing of the northern portion of the Sound occurred. The northern limit of this great lake thus is at present quite indefinite.

The outlet for all water escaping southward from fresh-water bodies in Puget Sound lies southwest of Olympia, through the col between the Sound and the Chehalis River, with an elevation of 120 feet A.T.

A swamp at the col drains both north and south. Within two miles of Puget Sound drainage from this swamp flows south to the Chehalis River and thence to the Pacific Ocean, 50 miles distant.

The narrowest place in the channel of the glacial stream which discharged over the divide is close to its inception, about $1\frac{1}{2}$ miles from Budd's Inlet. Here the width of the 120-foot channel is less than one-fourth of a mile. This is cut in the bed of a considerably wider channel, whose floor is 160 feet A.T. A definite terrace occurs here, and also in the swamp a mile distant at 140 feet. These three levels are seen repeatedly in the 17 miles of channel length, though their altitude descends and their distinctness is less marked farther south. The ancient outlet today contains Percival Creek north of the col, and Black Lake and Black River south of it.

At Gate, the Black Lake outlet channel joins the wide Chehalis Valley. At the debouchure occurs a considerable area of gravel spreading out into the larger valley from the north. The deposit presents a rather abrupt face down the valley. Its surface altitude is approximately 100 feet above sea-level. Farther down the Chehalis Valley, glacial gravels occur only at the mouths of tributary valleys from the north, none being found in a careful search for five miles immediately below Gate.

The genesis of the Gate gravels is evidently associated with the operation of the Black Lake outlet and their deposit here suggests slack water in the Chehalis Valley, standing at an altitude at Gate of about 100 feet.

The suggestion of standing water at Gate and in the Chehalis Valley, much beyond the limits of glaciation, and so topographically placed that ice could not close it if it were glaciated, turns one to a consideration of the sea-level at the time of Vashon glaciation and retreat.

In the study of the physiography of Puget Sound, various shell-bearing terrace fragments have been observed. Willis notes the occurrence of the lowest, 15–20 feet above present mean tide,[1] and Arnold has recorded one 40 feet above sea-level on the west side of the Olympic Mountains.[2] Terraces at both of these levels have

[1] Bailey Willis and G. O. Smith, *op. cit.*

[2] Ralph Arnold, "Geological Reconnaissance of the Olympic Peninsula," *Bull. Geol. Soc. Am.*, XVII.

been repeatedly observed by the writer, occurring on all important inlets of the Sound. Shell-bearing terraces at higher levels, though rarer, have been found at about 60 and 80 feet, and in three places 100 feet above present tide.

Of the marine shell-bearing terraces at the highest level, two are on the west side of Hood's Canal, and one at Tumwater on Budd's Inlet. On one of the Hood's Canal 100-foot terraces, the sod and forest soil are literally a mass of comminuted shell fragments to the depth of a few inches. The 80-foot terrace is present immediately below it.

Unless error has been made in these observations, there is here conclusive evidence that at some time subsequent to the fresh-water occupancy of Puget Sound's southern valleys, the land was 100 feet lower than now.

From the rare occurrence of the consecutively higher marine terraces of Puget Sound, and from the lack of any evidence to the contrary, it has been assumed that the series represents successive stages in a rising of the land which has been in progress throughout post-glacial time. On this supposition, the 100-foot terrace represents the level of sea water on first entrance into the Sound after the ice retreat from its northern portion. The 100-foot gravels at Gate and the 100-foot marine terraces of the Sound seem good evidence that the entire region was that much lower when the greater lake of Puget Sound discharged southward across the Chehalis-Sound divide during the retreat of the Vashon ice sheet. This lake then was but 20 feet above the sea at its lowest stage.

It is well established by the outlet channel that static water was held to its levels in the southern part of the Sound by ice in Admiralty Inlet during Vashon retreat. The limited amount of examination thus far possible has shown four rivers of the region to possess deltas at one or more levels between 120 feet and 160 feet A.T. The Des Chutes River has an old delta plain in the southern part of Olympia 160 to 170 feet high, and the Nisqually River dissects an old delta at Sherlock, three miles back from the present coast, the summit plain of which is about 160 feet high. Both deltas correlate with the 160-foot terrace in the outlet near Black Lake. They have been examined only cursorily thus far, and nothing is known concerninng lower stages.

Farther north occur the Redmond and Brinnon deltas, the former with correlating terraces for the three stages of the lake indicated by the outlet, the latter with but the lowest stage recorded. Associated with these deltas are respectively the York and Bothel, and the Poulsbo channels at appropriate altitudes, and each leading into a valley open through to the Black Lake outlet at the south.

Though the evidence of the two northern deltas may perhaps be of insufficient weight to establish the extent of the master lake as far north in the Sound as the Bothel and Poulsbo channels, yet it is quite suggestive of such extension. The levels must otherwise be explained as a coincidence of local ponding, and the greater lake must in such case be considered as having lowered from the Black Lake outlet earlier in the ice retreat, by tunnel drainage northward.

It is of much interest to note that there is nothing in any collected data concerning the various glacial lakes or the terraces of early marine occupancy which suggests tilting or warping of the region in the uplift which has taken place.

It seems fitting that to this lake of Puget Sound, with outlet southward through Black Lake channel and with levels controlled by that channel, a name should be given in tribute to the work of a geologist to whom our knowledge of the physiography of western North America must always be deeply indebted. In memory of Israel Cook Russell may this water body be known as *Lake Russell.*

In an article by Upham in the *American Geologist,*[1] the Black Lake outlet is noted and the suggestion made that a glacial lake probably existed in Puget Sound and discharged through the channel. Upham supposed the col to be 170 feet high. This article was not seen until the work on which the present article is based was all but completed, the outlet region having already been examined three times. Though having no influence on this work, it is hereby acknowledged as the first published notice of the existence of Lake Russell.

The writer is indebted to Mr. Bailey Willis for careful examination and criticism of the data presented herewith, and for valuable suggestions which have given broader conceptions and have modified conclusions in this paper.

[1] Warren Upham, "Glacial and Modified Drift in Seattle, Tacoma, and Olympia," *American Geologist,* XXIV, No. 4.

ON THE GLACIAL ORIGIN OF HURONIAN ROCKS OF NIPISSING, ONTARIO

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In the early (1846 ff.) reports of the Canadian Geological Survey there appear descriptions by Sir William Logan of a series of non-fossiliferous clastic rocks found on the west shore of Lake Temiskaming and north of Lake Huron. Logan correlated the rocks of the two localities and gave them the name Huronian. He believed them to be younger than and made up partly of detritus from the Laurentian, and his conclusions have been verified by later observers.

Recently these rocks have attracted more than local interest on account of the discovery of rich silver veins at Cobalt. As a result of their economic importance the rocks have been subjected to much closer examination than before and many interesting features have been noted. Among these are peculiar characters which are strongly suggestive of the existence of glaciers in Nipissing in early Huronian times. Dr. A. P. Coleman[1] who has made a study of these rocks from the standpoint of the glacialist, has gathered evidence from which he concludes that there is no doubt of the glacial origin of the basal conglomerate of the lower Huronian. It is purposed here to present some facts which bear on this question.

The chief rocks in this district are of the Archean and Algonkian groups. These are separated by a very marked unconformity and the interval was doubtless the greatest which occurred in the pre-Cambrian times. There is no good reason to doubt that for a long period of time the Archean rocks were being worn down by all or any of the erosive agents now active.

The Huronian series doubtless represent a portion of the secondary rocks thus formed, and they are entirely composed of detrital material. They are conveniently grouped into an upper and a lower series,

[1] "The Lower Huronian Ice Age," *Jour. Geol.*, XVI (1908), 149–58.

which are generally conformable but in some localities separated by a slight unconformity.

The upper series is made up largely of medium-grained feldspathic quartzite with a little conglomeratic material. It presents no unusual feature and doubtless represents the hardened accumulation of a feldspathic sand derived from siliceous holocrystalline igneous rocks of the Laurentian group.

The lower series is made up largely of conglomerate, shale, graywacke, and feldspathic quartzite. In many cases there is gradual

FIG. 1.—Huronian conglomerate near Temagami, Ont.

gradation vertically from one of these types to another. Less often there is a sharp division line. The composition of one stratum is often fairly constant for some distance; but in some cases a distinct change takes place in a few feet laterally as well as vertically.

The shales are for the most part of gray color, less often greenish black. Occasionally they are interbanded with layers of purple, green, and pale-gray colors. The chief recognizable minerals are quartz and altered feldspars, minute scales of chlorite and sericite, and small grains of epidote, titanite, and iron ores. In mineralogical and chemical composition they are not unlike green shales of other formations.

The quartzites are in most instances feldspathic and grade insen-

sibly into typical arkoses. They are usually very massive, fine to medium grained, and not unlike light-colored granite in appearance. It is often very difficult to determine their structure as there are seldom well-marked bedding planes. There are however instances in which the bedding is indicated by variations in the size and relative proportions of the various grains and other cases in which it is indicated by horizontal jointing. The rock is very largely composed of quartz and feldspar. Sericite and kaolin are prominent in light-colored varieties and chlorite in the darker. Titanite and iron

FIG. 2.—Huronian conglomerate, Temagami, Ont. Steel scale (in book) is one foot long.

ores are usually present in small quantity. The feldspar and quartz grains are often well rounded but quite as frequently angular or subangular.

Closely allied to the shales and arkoses are the graywackes. The chief recognizable constituents in these are feldspar, quartz, a dark chlorite, and a pale-colored mica. Less abundant are small particles of iron ore and epidote, while pyroxene and amphibole are rare. With the minerals are angular and rounded rock particles of various sizes. Rock of this type in some instances is found in massive beds of uniform character, very fine grained and of gray to greenish color. Similar material forms the matrix of much of the bowlder conglomerate.

FIG. 3.—Huronian conglomerate, Buffalo Mine, Cobalt, Ont. A common type, little evidence of stratification.

The conglomerate is remarkable for its heterogeneous appearance. Not only are the bowlders of a great variety of types but in many cases they show no evidence of arrangement according to size. Frequently one finds bowlders a foot in diameter scattered irregularly and sparsely through an aphanitic matrix of shale or graywacke, thus simulating glacial deposits. In other cases there are thick beds of shale quite free from such erratics. There are also beds of bowlders of nearly equal size packed close together and with but little of fine-grained matrix,

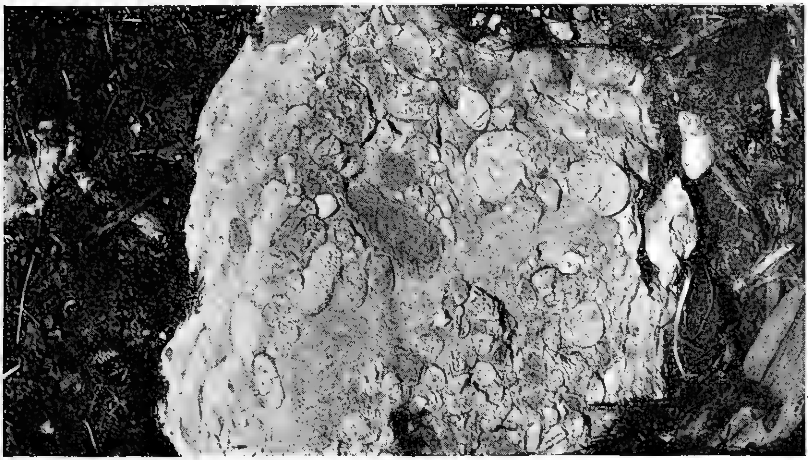

FIG. 4.—Huronian conglomerate, Buffalo Mine, Cobalt, Ont. A weathered surface of coarse facies.

as in an ordinary water accumulation of coarse gravel. In some instances the aphanitic beds are distinctly laminated as in ordinary water-laid clay, while again similar material forms a compact rock lacking in well-developed bedding planes.

As a general rule the large bowlders are well rounded or subangular; but there are occasional streaks containing markedly angular fragments. Dr. Coleman found some bowlders at Cobalt which show striae and concaved surfaces.

The matrix of the conglomerate, which is often graywacke and less often shale, contains numerous angular particles of quartz, feldspar, chert, and felsites. Particles of such shape are very characteristic of, though they are by no means found only in, glacial débris.

Where the contact of the conglomerate with underlying rocks has been found there is a noteworthy lack of alteration in the older rocks. If they were deeply disintegrated by surface weathering the material must have been removed by a very efficient agent. This again suggests ice action. In a few of the contacts the line of demarcation is less distinct, as is ordinarily the case with unconformities in water-laid sediments. Naturally the contacts of the latter type are not so likely to be found as those of the former.

FIG. 5.—Huronian conglomerate, Coniagas Mine, Cobalt, Ont. A horizontal exposure.

There has not yet been found a smooth or striated floor. The basal conglomerate, in some cases at least, has been formed *in situ* and is made up of detritus from the immediately adjacent rocks.

Professor Coleman does not consider that the lack of discovery of a characteristic glacial floor precludes the possibility of the material having been placed by ice, and refers to well-known instances in which such a floor is lacking.

The localities specially mentioned by Dr. Coleman are Cobalt and Temagami. Cobalt Lake, on which the town is situated, lies almost entirely in Huronian conglomerate. The conglomerate in turn lies in a deeper valley formed by rocks of the Keewatin group. It might be expected therefore that the coarser material in the conglomerates

would be largely detritus from these old greenstones and cherts; but such is by no means the case. The basal portion is made up

FIG. 6.—Huronian conglomerate on Keewatin slate. Near Temagami, Ont.

FIG. 7.—Coarse conglomerate on greywacke (Huronian). Temagami, Ont.

very largely of material similar to that which inclosed the old valley; but the greater portion of both bowlders and matrix is quite different. There are not now exposed any near-by hills from which these mate-

rials might have been brought down, nor is there good reason to believe that such hills existed in Huronian times. The nearest outcrops of Laurentian rocks from which many of the bowlders may have been derived are some miles distant. Many of the large bowlders are quite unlike any rocks which have been found in place in the district. Evidently ice was the most competent agent to bring such materials to their present position, and to deposit them in such a heterogeneous manner.

FIG. 8.—Huronian conglomerate, Trethewey Mine, Cobalt, Ont. Shows stratified and unstratified portions. Such well-banded portions are of quite small extent as compared with the unstratified. One of the streaks contains distinctly angular fragments.

At Temagami the conglomerate lies on Keewatin schists and at its base contains numerous fragments of them. The conglomerate also contains numerous rounded and subangular bowlders of rocks not found close by. The underlying rock presents a fairly fresh but not a smooth surface. The matrix of the basal conglomerate contains numerous well-formed rhombohedra of siderite, and similar crystals are abundant in shale and quartzite beds in the conglomerate. They were evidently derived by weathering from the adjacent iron formation and the crystals were growing freely contemporaneous with the mechanical deposition of clay, sand, and bowlders. It is probable

therefore that the conglomerate was formed under water and that there was carbonate in solution. If the larger erratics were brought by ice it was probably not land ice.

SUMMARY

In appearance the conglomerate-quartzite-shale series of the Huronian represents nothing so closely as compacted glacial and glacio-fluvial débris. The finding of striated and soled pebbles confirms the supposition of such an origin. The character of the contacts thus far found do not disprove that glaciers placed the basal conglomerate, though they suggest that such was not the case.

There are some sudden transitions from shale to coarse conglomerate which suggest that the earlier deposits may have been overridden by land ice. It seems probable however that part of the material was deposited under water and that floating ice contributed its load of glacier-derived material.

There is no reason for supposing that the thick bowlder-free beds of shale and graywacke are not ordinary water-laid sediments, though they may contain glacial floor.

EDITORIAL

Most good causes, as they come into popular favor, suffer from diversions, if not perversions, in the interest of other causes. Just now the good cause of the conservation of natural resources has reason to file a protest against being made the victim of the old device of promoting a weaker issue by a perverted use of the popularity of a stronger one. After a normal growth of two decades under the scientific guidance of the national Geological Survey, the doctrine of conservation has recently blossomed out into wide popular favor. This special blossoming has not been without artificial fertilizers from other than strictly scientific sources, but that need count little here or there if the blossoming be left to lead on to natural fruitage without hybridization. Now, however, come diversions and perversions. The protection of natural values against wastage is one thing, the possession of these values is quite another thing. The best conservation may not be correlated with the best ownership, all things considered. Ownership, desirable on other accounts, may be an obstacle to conservation, and ownership, otherwise undesirable, may be tributary to conservation. This is so because, in their fundamental nature, the problems of conservation and the problems of possession are distinct questions, each to be solved in its own way and on its own basis. They center in separate fields. The conservation of natural resources centers in the scientific and the technical; the right of ownership and the most desirable distribution of ownership center in the political and the sociological. The best conservation of the soil is not necessarily dependent on the most desirable partition of the land. The small farmer often impoverishes his farm, while the estate of the millionaire fattens under scientific management. To divide Alaska into 90,000,000 moieties and give each of us one, would not settle the problem of the highest utilization of the Alaskan resources. To form an absolute monopoly with 90,000,000 stockholders—call it "government" or otherwise, as you please—would still leave the problem of conservation untouched. To permit fewer individuals and more corporations to pay the price and divide the ownership,

in accordance with our present practice, however proportioned, would equally leave the problem of conservation to be worked out on its own grounds. And so, though in like manner all questions of the possession and distribution of values be marshaled under extreme individuality, extreme monopoly, or some combination of individuals and corporations lying between these extremes, all are alike political and sociological in nature and, however they may issue in practice, they leave the scientific and technical problems of conservation of natural resources to be solved on their own bases. And these solutions must be fundamentally much the same under any political or sociological system.

So obvious is all this that it can only be a careless lapse into confusion of thought, or else a wilful perversion of what is legitimate in the arts of persuasion, for an advocate of political or sociological measures to glide without a note of warning from a conservational premise which commands universal assent to a political conclusion respecting ownership or distribution of values which has no logical relation to conservation, and may even be incompatible with its highest realization. In recent months we have perhaps met such perversions or confusions of thought quite as often as legitimate arguments for true conservation. Fallacies usually reveal themselves in the end and hurt the cause in behalf of which they are urged, and these perversions must ultimately stand in the way of the wisest provisions for the distribution of natural values in behalf of which they are putatively invoked. No class of men bear a more urgent commission to keep the currents of thought clear and ethical respecting our natural resources than geologists, for, more than any others, they have, as a matter of history, been the fathers of the real conservation movement. Hence this note on the untoward set of a sinister current.

T. C. C.

Reviews

Comparison of North American and European Glacial Deposits. By FRANK LEVERETT, Ann Arbor, Mich. *Zeits. f. Gletscherkunde* (1910), IV, 241–316; Pls. V.

Intercontinental comparisons of this class may be made from the viewpoint of an individual worker, or from that of a representative of a special class of workers, or from that of an analyst of the whole body of current conceptions. Each viewpoint has its appropriate place and value, and each comparison must be adjudged on its own basis. The comparison of Mr. Leverett is individual rather than representative or composite. This gives occasion to note the reach of the personal studies that form the basis of the author's perspective. No one is more intimately conversant with the later glacial deposits of the plains of the United States from the Alleghenies to the Mississippi than is the author of this comparison. With the equivalent deposits east of the Appalachians, west of the Mississippi, and north of the national boundary, the author's familiarity comes rather from occasional excursions and secondary sources than from personal studies. With the older Labradorean formations east of the Mississippi the author's familiarity is also intensive, and this intimate knowledge extends measurably to the tract closely bordering the Mississippi on the west, but not in equal degree to the formations of the Missouri basin, to the glacio-fluvial deposits of the Lower Mississippi valley, or to those of the Atlantic coast. The montane field of western America lies outside the author's individual purview.

To this intensive basis in American study, Mr. Leverett has recently added a year's inspection of the European formations, with Berlin as a working center and German interpretations as a point of departure. His field studies lay chiefly in the German lowlands and in the Alps, with a very cursory glance at the British field.

These salient features of the author's experience may serve to orient the psychologic plane from which the comparison is made and to foreshadow the selection, emphasis, and coloration which might naturally arise from the author's point of view.

In full harmony with these, the preliminary glance over the makeup of the paper brings at once to view the obvious fruits of the intensive habit.

These constitute a notable part—and, it will be agreed, a most valuable part—of the paper. As by instinct, here and there the author drops into details of location and measurement, and the text takes shape more as a record of local facts than as a generalized intercontinental comparison, as on pp. 266–73, where the successive paragraphs are headed, "Basel," "Eglisau," "Leutkirch," "Drau Valley," "Lake Garda," "Cantù, Italy," "Dora Baltea," "Rivoli," and "Bièvre-Valloire"; with similar local treatment on pp. 283–95, and elsewhere. Besides contributing such local observations from the viewpoint of an American glacialist, the author earns our thanks by giving a convenient map of the limits of "The Old Drift," "The Middle Drift," and "The Young Drift" of the German lowland, to the construction of which he himself appears to have made local contributions.

The comparison itself is introduced under the head of "The Oldest Drift." America here makes its bow under an apology, as it were, for the buried state of the oldest drift in the Keewatin field and the scanty, scattered, weathered, remnant nature of the Jerseyan drift. But in reality these ragged weathered remnants tell the very story of age that most becomes a venerable drift. It is hard to pass complacently over so light a treatment of the worn and aged Jerseyan formation. To put the still more scant remnants of the old drift of the Allegheny Valley in their place as more representative but emphasizes the personal viewpoint which runs through the whole comparison and gives it at once its values and its limitations.

In assembling the group of oldest glacial deposits of the two continents, the old drift of the Allegheny basin (with some reservation), the Jerseyan east of the Alleghenies, and the pre-Kansan of the Mississippi Valley, as the American correlatives, are matched with the Scånian of north Germany, the Günz of the Alps, and the older Deckenschotter of the Alpine foreland. The oldest Deckenschotter however has a better correlative in the oldest member of the Columbian group, bordering the Jerseyan drift, both being outwash aprons, and in the massive Natchez formation of the Mississippi outwash train, and better still—because of similar topographic relations—in the remnants of old outwash sheets that spread forth from the ancient glaciers of the Uinta, Wasatch, and other montane centers of the Cordilleras, which are unmentioned. It would be ungracious to lay stress on this, did not the American side of the comparison, and withal the rounder and truer view, suffer from the neglect of some of America's most significant formations even when they have been fairly well worked. It may be noted also that the Günz drift has its best American correlatives in the Cordilleras.

For the first interglacial series, the Aftonian of America is compared

with the Paludinenbank of Germany, the Norfolkian of England, and the Günz-Mindel interglacial beds of the Alpine region.

As the second glacial series, the Kansan of the Keewatin field, and, questionably, the old deposits of the Allegheny Valley as a doubtful representative of the Labradorean field, are brought into comparison with the Lower Diluvium of the German lowlands, the Old Drift of England, the Mindel of the Alps, and the younger Deckenschotter as the associated outwash deposit of the last. The American correlatives of the last, in kind, are passed over.

The representatives of the second interglacial stage are the Yarmouth and the pre-Illinoian loess, on the American side, the Rixdorf of north Germany, unnamed beds in central Russia, and the Mindel-Riss interglacial deposits of the Alps, on the European side.

As representatives of the third glacial stage, the Illinoian of the Labrador field and doubtfully the "so-called Iowan of the Keewatin field (Illinoian ?)" are put into correlation with the Middle Drift of the north German lowland and the Riss drift of the Alps.

The third interglacial stage brings into comparison the Sangamon soil of the Labradorean field (no equivalent in kind in the Keewatin field) with the Riss-Würm interglacial deposits of the Alps. The main loess deposits of both the American and the European fields are discussed in this connection and made largely interglacial and eolian.

Only four glacial stages are recognized and the comparison ends with the fourth group, which embraces the Wisconsin series of America, the Upper Diluvium of north Germany, the Young Drift of England, and the Würm beds, with the associated Niederterrassen of the Alpine region. The glaciation of the Riesengebirge and the Schwarzwald are also touched on in this connection.

In the summary, some qualifications of the correlations are introduced, the most notable of which is the statement that "the European deposits seem to contain nothing that correlates clearly with the Illinoian drift." The middle drift of north Germany and the Riss, "though standing as representatives of the third glacial stage in their respective regions, each seems to be younger than the Illinoian drift."

It is in the grouping of this third stage and in the treatment of the Iowan that there is likely to be awakened the strongest dissent from the comparison of Mr. Leverett if it be considered—as it is liable to be considered—a representative rather than an individual correlation. It is important, the rather, to note that in the author's own point of view, the third stage, the Middle Drift, presents the most notable anomalies. There is little doubt

that most American glacialists will agree, each in his own way, that the interpretations of the middle drift of America, if we may use the term rather broadly, are those that most invite question and perhaps further readjustment. And so a few of the salient features of the shifting history of American opinion on the middle drift may be pertinent to this review. By American middle drift let us understand the formations that lie between the Aftonian interglacial beds that cap the lowest till and the base of the declared glacial sheets of Wisconsin age.

In an early comparison of American and European glacial formations put in print sixteen years ago in the revised edition of Geikie's *Great Ice Age* (1894, p. 774), the American deposits were given a threefold grouping, with a basal member, the Kansan, a middle member, the Iowan, and an upper member, the Wisconsin, using here the simplified forms the terms subsequently took. The first, the Kansan, was made to embrace the till below the "Forest Beds" and the "Noah's Barn-Yards" that were then supposed to form a common interglacial horizon; the second, the Iowan, was made to include the till above the "Forest Beds" and below the young moraine-ridged sheet which was made to constitute the third or upper division, the Wisconsin. This last division has held its place and name with firmness throughout and shows no signs of instability, but the two earlier divisions have suffered a serious shifting of names and of interpretations, and the end is perhaps not yet at hand. The name Kansan has been shifted from the sub-Aftonian till to the super-Aftonian till originally called Iowan. The term Iowan thus displaced has been transferred from the middle drift to the uppermost and least member of the grouped beds originally covered by the term. The reasons for these shifts seemed cogent to the workers in the Iowan field at the time they were made and perhaps seem so still. They were accepted with slight reluctance by the glacialist who had given the terms their original applications. The cogency of the reasons for the changes has, however, from his point of view, largely disappeared with the progress of study, and if it were practicable to return essentially to the original usage, making the sub-Aftonian till Kansan and the super-Aftonian till Iowan, and to take the exceptional exposures of both formations near Afton Junction, Iowa, as the types, as was originally done, it would seem to him to accord best with the inherent fitness of the case. Particularly does this seem so in the application of the term Iowan, for the super-Aftonian till not only has a broader and more distinctive expression in Iowa that anywhere else, but it is the greatest of Iowa's drifts; it is inherently the Iowan drift. When the shift of terms was made, it was supposed that the uppermost till sheet in eastern Iowa with

its peculiar youthful typography, accidented by remarkable granite bowlders, set superficially, embraced all the upper drift down to the "Forest Bed," in other words all of "the Upper Till" of McGee's classical paper on the drift of northeastern Iowa. As this upper till of McGee was the type of the East Iowan (Geikie's *Great Ice Age*, 760–62), the name naturally followed the new interpretation. The youthfulness of the surface and the freshness of the bowlders of this uppermost formation seemed to force its separation from the well-eroded deeply-weathered sheet which overlies the Aftonian beds at their typical locality. It has since been found, however, that the fresher features of the Iowan belong only to a thin superficial formation, and it will probably now be agreed by most experienced workers familiar with the region that the main part of McGee's upper till is to be correlated with the super-Aftonian till at the typical locality, thus restoring, in large measure, the original applicability of the term.

This sketch, even in its incompleteness, may serve to give a measure of historic insight into the embarrassments that attend the correlation and nomenclature of the American middle drift.

Respecting the newer divergencies of opinion implied in Mr. Leverett's paper, which involve the suggested dismissal of the Iowan altogether, as a distinct formation, or else its grouping under the Illinoian, it is appropriate here to urge restraint, patience, and equipoise, for the distinguishing phenomena, while pronounced and peculiar, are subtle in their gradations and singularly puzzling.

T. C. C.

The Middle Devonian of Ohio. By CLINTON R. STAUFFER. Geological Survey of Ohio, 4th Ser., Bulletin No. 10. Pp. viii + 204, 17 plates. Columbus (1909), 1910.

The first chapter of this bulletin is devoted to a "General Discussion of the Middle Devonian," which is considered under three headings. The first part is a "Historical Sketch" in which the literature of the Middle Devonian formations is carefully and fully reviewed. This is followed by a consideration of "The Middle Devonian in Adjoining Territory," in which the greatest amount of space is given to the equivalent formations of Indiana and Michigan, which have also been studied by the author in the field. In the closing part of the chapter is a "General Description of the Middle Devonian" formations, which in Ohio are the Columbus and Delaware limestones and the Olentangy shale. The Middle Devonian

rocks in Ohio outcrop in three districts, the most extensive of which is a belt with an average width of ten to twelve miles extending from the Ohio River across the central part of the state to the islands in Lake Erie, north of Sandusky, although the limestones do not extend south of Pickaway County. The second district, in the vicinity of Bellefontaine, is in the western part of the state; while the third is a somewhat crescent-shaped area in the northwestern part of the state, sweeping around from the Michigan line to that of Indiana.

The second chapter, which is devoted to a "Discussion of Sections and Faunas," contains a large number of sections of the formations under consideration in Ohio with lists of their fossils. The Columbus and Delaware limestones of Central Ohio have been subdivided into thirteen zones which are indicated by letters ranging from A, which represents the basal conglomerate of the Columbus limestone resting on the Monroe limestone, up to M at the top of the Delaware limestone. Each zone is fossiliferous, with the exception of the lowest one, or Zone A, and following the lithologic description of each one is a list of the fossils common to the zone. In regard to correlation with the standard formations of New York, the conclusion is reached that the Columbus limestone represents the Onondaga limestone and the Delaware limestone, and Olentangy formation the Marcellus shale and Hamilton beds of that state.

In chapter iii "The Relationships of the Middle Devonian Faunas of Ohio" are very fully discussed and it is shown that the Columbus fauna is composed of two elements, one of which came from the north and the other from the south. The last chapter is devoted to "Notes on and Description of Species," in which twelve new species and one variety are named and described.

The bulletin is illustrated by seventeen plates, thirteen of which give views of characteristic portions of the formations described. One is a "Hypothetical Map of the Middle Devonian Sea during Columbus Time" and another of the same sea "During Delaware-Olentangy Time." The last two plates are illustrations of fossils showing the new species which were drawn by Miss Edith Hyde.

The bulletin as a whole gives a scholarly account of the Middle Devonian formations of Ohio and contains a larger amount of information concerning them than any other published work. From a geological standpoint it is an interesting and valuable bulletin ranking among the best published by the Geological Survey of Ohio.

C. S. P.

Petrological Abstracts and Reviews

Edited by ALBERT JOHANNSEN

Announcement.—With this number of the *Journal* a beginning is made in the publication of a series of abstracts and reviews of petrographical papers which it is hoped may be continued in each issue in the future. Whether this will be possible or not will depend largely upon the co-operation of petrologists. With the increasing number of petrographical descriptions, reading and reviewing all articles has become a work too great for one man to accomplish in his spare time, and it is necessary to ask the assistance of all petrographers who are interested in keeping these abstracts up to date. This work was begun too late to cover all the recent literature, but great interest has been shown by the few petrographers who have been consulted, and much aid has been promised for future numbers. It is hoped that authors will themselves send in short summaries of their papers, promptly upon publication, giving reference to publication, volume, etc., as in the abstracts here published. It is especially desirable that new analyses, new methods of determination, and new instruments, be fully described. Summaries and separates for abstracts may be sent to Albert Johannsen, Walker Museum, The University of Chicago.

Barbier, Ph. "Sur un caractère chimique différentiel des orthoses et des microclines," *Comptes Rendus de l'Académie des Sciences*, 1908, CXLVI, 1330.

Spectroscopic analysis of the chlorides of the bases extracted from twenty-five orthoclases and twenty microclines shows that the orthoclases invariably contain small quantities of either lithium or rubidium, or both together, while the microclines contain neither. The author concludes that orthoclase constitutes a definite species characterized by monoclinic form and the presence of small quantities of lithium and rubidium, and that it therefore can be distinguished chemically from microcline.

F. C. Calkins

DUPARC, LOUIS. "Recherches Géologiques et Pétrographiques sur l'Oural du Nord," Pt. III: Le bassin de la Haute-Wichéra, *Mémoires de la Société de Physique et d'Histoire Naturelle de Genève*, 1909, XXXVI, fasc. 1.

Pp. 53–114 are devoted to the petrography of diabases and pre-Devonian metamorphic rocks.

The diabases are of ordinary types, essentially composed of plagioclase and augite. The optical properties of the pyroxene and its alterations are fully described.

The metamorphic rocks comprise quartzites, amphibolites with albite and epidote, albite-chlorite schists, glaucophanites with albite and epidote, sericitic albite gneiss, quartz-sericite schist, and quartzitic schist. Numerous rock analyses are given and the amphibolites are said to be derived from diabases. The optical properties of the amphiboles are described with much detail. Amphiboles related to glaucophane occur in many of the schistose rocks.

F. C. CALKINS

FINLAYSON, A. M. "Petrology and Structure of the Pyritic Field of Huelva, Spain," *Geol. Mag.*, 1109, VII, 220–29. Figs. 3, pl. I.

The pre-Cambrian rocks which occur in this area consist of gneisses, hornblende schists, crystalline and metamorphic limestones, succeeded by less altered schists and phyllites. Cambrian schists with quartzites and greywackes are conformable with the upper members of the crystalline series. Granites of varying composition occur as a series of intrusive bosses. Rhyolite, trachyte, syenite, and monzonite porphyries occur and are thought to be intrusive in agreement with Vogt and opposed to Klockman. Basic intrusions, consisting of diabases, augite porphyrites, dolerites, and augite diorites are mentioned.

ALBERT D. BROKAW

GOLFIER, J. "Recherche des paramètres qui caractérisent les types classiques de roches éruptives," *Bull. Soc. Geol. Fr.*, 4th ser., 1908, VIII, 55–64.

The author attempts to define chemically the divisions of the current classification developed by Rosenbusch and others.

The "parameters" used for the purpose are certain especially character-

istic ratios derived as follows: Let the atomic proportions of Si, K, Na, Ca, Mg, Fe, be represented by s, k, n, c, m, f. Then

$$A=\frac{k+n}{k+n+c+m+f}\times 100,\quad Sa=\frac{s}{k+n}$$

$$MF=\frac{m+f}{k+n+c+m+f}\times 100,\quad Ss=\frac{s}{k+n+c+m+f}$$

It is found that in the second edition of Rosenbusch's *Gesteinslehre* the names of analyzed rocks, with relatively few exceptions, are used in accordance with the following scheme:

<table>
<tr><th colspan="2"></th><th>Sa>5.5</th><th>Sa<5.5
>4.15</th><th>Sa<4.15>2.9</th><th>Sa<2.9</th></tr>
<tr><td colspan="2">A>50
Alkaline magmas</td><td colspan="2">Granites</td><td>Alkali syenites</td><td>Eleolite syenites</td></tr>
<tr><td colspan="2">A<50>25</td><td>Diorites</td><td>Normal syenites</td><td colspan="2">Theralites</td></tr>
<tr><td rowspan="2">A<25</td><td>MF<75
Mixed magmas</td><td colspan="2">Ss>1.1, Gabbro</td><td colspan="2">Ss<1.1 Shonkinites</td></tr>
<tr><td>MF>75
Ferromagnesian magmas</td><td colspan="4">Peridotites</td></tr>
</table>

Rosenbusch's syenites are divided into "normal" and "alkali" syenites, while his essexite, theralite, and shonkinite and ijolite-missourite families fall in the "theralites" and "shonkinites" of the table.

F. C. CALKINS

HILLEBRAND. W. F. "The Analysis of Silicate and Carbonate Rocks," *Bull. U.S. Geol. Survey No. 422*, 1910. Pp. 239. Figs. 27.

A revision of *Bulletin 305*. The following are the more important changes and additions. The effect of fine grinding upon the ferrous iron content is discussed in the chapter on the preparation of the sample, and again in the chapter on the determination of ferrous iron. To minimize the error due to oxidation the sample may be ground in absolute alcohol. This apparently does not reduce ferric minerals.

The chapter on water has been rearranged and is introduced by a section on the rôle of hydrogen in minerals, in which a provisional classifica-

tion of the condition of hydrogen in minerals is developed. The author advocates the weighing of the air-dry powder and determination of moisture rather than the weighing of the perfectly dried sample, as the latter takes up water on the unavoidable exposure to the air during weighing, etc.

A considerable addition is made to the chapter on the determination of titanium, with the view to minimizing the error due to the bleaching effect of alkali salts on the color produced by hydrogen peroxide.

A new indirect method for determining fluorine, devised by Steiger and modified by Merwin, is introduced. This method is based on the fact that fluorine has a powerful bleaching effect on the yellow color resulting from the oxidation of a titanium solution by means of hydrogen peroxide. Steiger's and Merwin's diagrams are introduced.

A number of alterations of minor importance have also been made.

ALBERT D. BROKAW

JOHANNSEN, ALBERT. "Some Simple Improvements for a Petrographical Microscope," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 435–38. Figs. 4.

The writer describes (1) a rotating upper nicol in which the annoying reflection of light from the surface is overcome; (2) a permanently attached combination wedge, combining a gypsum plate and a combination quartz-mica wedge in a metal casing. An indicator shows the order of the interference color appearing in the field; (3) a rotating lower nicol for observing very slight changes of pleochroism; (4) improvements to the Hirschwald stage.

ALBERT D. BROKAW

LACROIX, A. "Sur l'existence à la Côte d'Ivoire d'une série pétrographique comparable à celle de la charnockite, *Comptes Rendus de l'Academie des Sciences*, 1910, CL, 18–22.

The rocks described have a vast development in the western part of the Gold Coast territory. They range from hypersthene granite, almost wholly composed of quartz and feldspars, to a norite free from quartz and containing at least 50 per cent of hypersthene.

Four analyses are given. These illustrate the following chemical characteristics; relatively high iron and magnesia, varying inversely as SiO_2, (71.80–54.33); slight variation in soda (3.52–4.35), rapid decrease in potash (4.11–0.59) as silica decreases; relatively small variation in lime

(2.20–5.60) which is almost wholly contained in plagioclase with 21–43 percent An.

The great interest of the rocks lies in the fact that they belong to a rare family supposed by Rosenbusch to be possibly co-ordinate with the alkali and lime-alkali families. These are principally developed in three other regions: India, S. Norway, Canada, and the Adirondacks.

The magmatic relations to the harzburgites, norites, and diabases, partly hypersthene-bearing, of Guinea and Sierra-Leone are still to be determined.

An alkali granite containing a soda amphibole is found farther north surrounded by granites of non-alkaline facies.

Ordinary biotite granites are abundant about the sources of the Niger.

F. C. Calkins

Loughlin, G. F. "Intrusive Granites and Associated Metamorphic Sediments in Southwestern Rhode Island," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 447–57. Maps 2.

From his studies in southeastern Connecticut and southwestern Rhode Island, the author became convinced that all of the granites of that area are parts of one batholith, not of pre-Cambrian age, but intrusive into rocks which have been mapped as Carboniferous. In a former paper, not yet published, a detailed report was made of the Connecticut area. The present paper gives the results of a continuation of the work eastward into Rhode Island.

In the Connecticut area the granites, which the writer calls the Sterling granite series, include normal biotite granite, porphyritic biotite granite, and alaskite; the latter cutting the other two varieties. All are intrusive into the sedimentary series. In the Rhode Island area the same rocks are found, supplemented by a later intrusion, represented by the granite found at Westerly, R.I. Both the sediments and the Sterling granite are cut by dikes of the Westerly granite, which differs from the Sterling granite only in containing a higher percentage of plagioclase.

The author concludes: (1) The Westerly granite is closely related to the Sterling granite and is considered its latest exposed phase. (2) The Sterling granite batholith is continuous from eastern Connecticut to Narragansett Bay, R.I., and includes granite formerly thought to be pre-Cambrian. There are no pre-Cambrian rocks in Rhode Island south of the Washington-Kent county line. (3) The Sterling granite is intrusive into all the sediments with which it is in contact, and its intrusion accompanied metamorphism

and folding. (4) The time of the intrusion is correlated with that of the Appalachian Revolution. (5) The Kingstown sediments were derived principally from felsite porphyry, micrographic granite, and possibly more basic igneous rocks.

ALBERT JOHANNSEN

NOBLE, L. F. "Contributions to the Geology of the Grand Canyon, Arizona. The Geology of the Shinumo Area, Pt. I," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 369–86.

Describes the Archean rocks (Vishnu) of the area as consisting of a complex of quartz, mica, and hornblende schists, invaded by a batholithic mass of quartz diorite and injected by veins of pegmatite and aplite. These veins are of two ages, the older being folded with the schists, while the younger cut both the schists and the quartz diorite. No attempt is made to work out the general structure of the complex on account of the limited exposures.

ALBERT D. BROKAW

PRIOR, G. T. "On an Analcite Basalt from Rathjordan, Co., Limerick," *Min. Mag.*, 1910, XV, 315–17. Figs. 2.

The rock from Rathjordan has been described by Hull and Alport. According to the latter it is a fine-grained, black basalt which consists of a groundmass of innumerable small grains of augite, magnetite, and amorphous glass, in which are pseudomorphs of altered olivine and feldspar. The present writer adds that in the supposed glassy groundmass there are also thin needles, probably apatite, and some isotropic material which, under the microscope, resembles leucite.

A small portion of this isotropic material was isolated and subjected to microscopical and chemical tests. There were strong reactions for sodium while none were obtained for potassium. He concludes, therefore, that most of the supposed leucite is probably analcite. In order to check this conclusion an analysis of the rock was made which appears as follows: SiO_2, 40.81; TiO_2, 3.86; Al_2O_3, 13.08; Fe_2O_3, 6.40; FeO, 7.20; MnO, 0.07; CaO, 10.12; MgO, 10.03; Na_2O, 2.43; K_2O, 0.31; P_2O_5, 0.88; H_2O at 110°C., 0.82; H_2O above 110°C., 3.97. The small amount of potash shown by this analysis seems to confirm the above conclusion. The rock is therefore an analcite-basalt. This analysis is compared with one of a leucite basalt from Bohemia, and one of an analcite basalt from Colorado. In the case of the latter rock, Cross argues, that judging from

the freshness of the other constituents present, the analcite is probably primary. However no such an argument applies to the analcite of the Rathjordan basalt as the rock is much altered. The author suggests that possibly this rock was originally a leucite basalt and that the leucites have been subsequently altered to analcite.

CLARENCE W. RUSSELL

RANSOME, F. L., EMMONS, W. H., and GARREY, G. H. "Geology and Ore Deposits of the Bullfrog District, Nevada," *Bull. U.S. Geol. Survey, No. 407*, 1910. Pp. 130. Figs. 20, Pl. 13.

Two areas of pre-Tertiary crystalline rocks are described. The first consists of quartzite, quartz-biotite and quartz schist, grading through calcite schist into nearly pure marble. A few pegmatite veins and a larger number of quartz veins cut the schists. The schists are overlain by limestone presumed to be Silurian.

In the second area the crystalline complex consists chiefly of quartz-biotite injection schist, pegmatite, and augen gneiss. A "sheared diorite" is thought to be a dike which cut the sedimentaries previous to their metamorphism. A quartz diorite dike cuts the schists and pegmatite and with them is cut by a subsequent diorite dike.

The Tertiary volcanic rocks are described as consisting of sixteen rhyolite flows, five basalt flows, one flow of quartz latite and one of quartz basalt, two sedimentary tuffs, an intrusive rhyolite porphyry, dikes of plagioclase basalt and an intrusive leucite basanite. This rock falls into a subrang of the quantitative classification which has not been previously represented by an analysis from the United States. Five analyses of Tertiary igneous rocks of the region are included in the report.

The Introduction and the Economic Geology section are by Ransome; the General Geology section by Emmons and Garrey.

ALBERT D. BROKAW

TRAVIS, C. "On the Behavior of Crystals in Light Parallel to an Optic Axis," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 427–34. Figs. 2.

A mathematical explanation of the fact that a section of a biaxial crystal cut normal to an optic axis appears uniformly illuminated in parallel light between crossed nicols. The author concludes: (1) Interior conical refraction, in a strict sense, plays no part whatever as a cause of the phenomenon; (2) The cause is to be found in the fact that so-called parallel

light has commonly a considerable divergence; (3) In any given case, the observed intensity of illumination is equal to the average intensity of that portion of the interference figure bounded by the limits of the pencil of light used.

ALBERT JOHANNSEN

WRIGHT, FRED EUGENE. "A New Ocular for Use with the Petrographic Microscope," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 415–26. Figs. 10.

A description of an ocular with which the birefringence, the optic axial angle, when one or both optic axes appear within the field of vision, and the extinction angle of a mineral in thin section may be measured.

ALBERT JOHANNSEN

WRIGHT, FRED EUGENE. "A new Petrographic Microscope," *Am. Jour. Sci.*, 4th ser., 1910, XXIX, 407–14. Figs. 4.

The author describes a new petrographic microscope, designed and constructed in the workshop of the Geophysical Laboratory at Washington, and specially adapted to the investigation of the optical properties of minute grains of artificial preparations. The principal differences between this and the usual petrographic microscopes are: (1) Both nicols revolve simultaneously, the connection between the two being a rigid bar; (2) The upper nicol always remains in the tube and the substage nicol is inserted or withdrawn on passing from ordinary light to crossed nicols; (3) The sensitive plate is inserted just below the condenser; (4) It has a simple mechanical stage; (5) The Bertrand lens is mounted in a sliding collar which permits of different magnifications of the interference figure; (6) An iris diaphragm immediately below the ocular is intended for use when observing interference figures directly by the Lasaulx method without the ocular and Bertrand lens; (7) An Abbe condenser is used, and with it a large nicol prism, or an Ahrens prism, 15 mm. edge, after the manner of the Fuess microscope No. I*a*. With this arrangement the entire condenser lens system remains in position and its upper lens need not be removed when low-power objectives are used.

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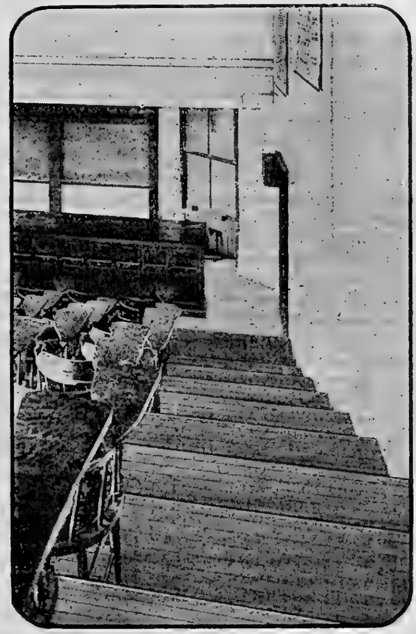
The Investigation of Dust Conditions in Schools

Positive Proof That Dust is a Menace to Health

IT is only in recent years that science has sought to improve the hygienic conditions of our school buildings. Among the most interesting and enlightening of the various experiments conducted, have been those dealing with dust and its relation to the transmission of contagious diseases.

Webster defines "dust" as "fine, dry particles of earth or *other matter*, so comminuted that they may be raised and wafted by the wind." These dust particles may, for purposes of discussion, be grouped in two classes—first, those larger particles which are easily discernible by the naked eye; and second, those lesser particles, invisible except under a glass and strong illumination. The various definitions of "dust" describe it as being made up of earth and *other matter*—which may be either mineral, vegetable or animal. Bacteriological research demonstrates that a very large proportion of the "other matter" belongs to the "second class" and is composed of dangerous disease germs. This being the case, the bacilli of Tuberculosis, Typhoid, Diphtheria, Pneumonia and other equally menacing diseases are easily transmitted from place to place, and it naturally follows that in places of public assembly the danger of dust contagion is greatest.



In class-rooms, lecture halls, laboratories, auditoriums or other departments of our schools and colleges, dust is present in its most dangerous form. Pupils naturally track in from out of doors large amounts of dust and dirt—the frequent shifting of classes, the constant movement of feet and the various drafts and air-currents produce a continuous circulation of the dust and bacteria, dangerous to anyone breathing it.

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AN EXPERIMENTAL INVESTIGATION INTO THE ACTION OF DIFFERENTIAL PRESSURE ON CERTAIN MINERALS AND ROCKS, EMPLOYING THE PROCESS SUGGESTED BY PROFESSOR KICK

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CONTENTS

INTRODUCTION

In a paper which appeared some years ago the results of an experimental investigation into the flow of marble were presented.[1] As this line of investigation seemed to be one which promised to yield additional results of interest if further developed, a grant was made to the present writer by the Carnegie Institution of Washington for the continuance of this work. A more complete equipment for

[1] F. D. Adams and J. T. Nicolson, "An Experimental Investigation into the Flow of Marble," *Phil. Trans. Royal Soc. of London* (1901), Ser. A, CXCV, 363–401.

experimental study was thus secured, the phenomenon of the flow of marble was further studied, and the investigation was extended to other rocks and to various rock-making minerals.

In the present paper it is proposed to describe briefly the results obtained in a single line of the investigation—that in which a method suggested many years ago by Professor Kick was followed. This method, however, while giving certain interesting results, especially with the softer and more plastic rocks, has proved to be less suitable for the development of high differential pressure and for otherwise reproducing the conditions which obtain in the deeper parts of the earth's crust, than the method suggested by the present writer and employed in the research into the flow of marble to which reference has been made. A brief statement of the results obtained by the latter method will appear elsewhere shortly,[1] while the full and detailed results of the whole investigation will eventually be issued by the Carnegie Institution of Washington in a special publication.

In carrying out experiments on the action of differential pressure with a view to reproducing more or less accurately the conditions of pressure which obtain in the deeper parts of the earth's crust, where flow is developed, it is manifestly quite useless to attempt to reproduce these conditions by simply submitting the materials to be investigated to compression in a testing machine, as is done in testing the strength of building stones. Differential pressure is certainly developed in such cases, but it consists merely of the ordinary atmospheric pressure on the sides of the test-piece while the enormously greater pressure exerted by the testing machine acts in the vertical direction. It is necessary to increase the lateral pressure and make it in some degree at least approach the measure of that exerted in a vertical direction if the pressure conditions of the zone of flow in the earth's crust are to be reproduced.

DESCRIPTION OF KICK'S METHOD

To secure this lateral pressure experimentally Kick[2] devised his method. This consists in making a box of some strong and at the same time ductile metal, such as copper, placing in it a specimen of

[1] See *Amer. Jour. Sci.* (June, 1910), and following numbers.

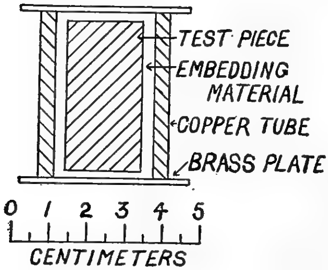
[2] "Die Principien der mechanischen Technologie und die Festigkeitslehre," *Zeit. des Ver. Deut. Ingen.* (1892), XXXVI, 919.

the material to be experimented upon, and then filling the space between the two with some embedding material which may be poured in as a liquid but which on cooling will solidify into a mass which is susceptible of deformation under pressure and which can, at the conclusion of the experiment, be removed by heat or in solution. The whole is then submitted to the action of a powerful press and squeezed down. The resistance to deformation offered by the copper as well as by the embedding material itself is transmitted through the embedding material to the specimen, which thus receives a very considerable amount of lateral support, or is submitted to a very considerable amount of lateral pressure as the deformation proceeds. After the completion of the experiment the embedding material is removed and the specimen recovered and examined. This method is easily followed, experiments can be made quickly, and but little mechanical skill is needed in preparing the materials for the purposes of the experiment. It can, however, be used only in experiments carried out at ordinary temperatures, and it is impossible in using it to determine accurately the pressure to which the specimen is being subjected, for the pressure is divided between the box, the embedding material, and the specimen itself. Furthermore, the pressures which are obtained by this means are not so great as it is desirable to employ in some cases. Kick, however, succeeded in this way in developing permanent deformation in rock salt, talc, gypsum, fluorspar, and marble. Two papers by Rinne,[1] which have appeared more recently and while the present investigation was being carried out, also present an account of certain experiments in which Kick's method was employed and in which rock salt, sylvine, and marble were deformed.

In the present investigation stout copper pipe was used, the standard size known as "one-inch iron-pipe size" being usually employed. This has an internal diameter of 1.063 inches and is made of material having a thickness of 1.125 inches. From this lengths were cut off to suit the specimen to be examined. The piece of tube, having smoothly finished ends, was placed in an upright position on a glass

[1] "Beitrag zur Kenntniss der Umformung von Kalkspathkrystallen und von Marmor unter allseitigem Druck," *Neues Jahrb. für Min.*, etc. (1903), I, 3, s. 160; "Plastische Umformung von Steinsalz und Sylvin unter allseitigem Druck," *ibid.* (1904), I, 3, s. 115.

plate and a portion of the embedding material (molten alum or whatever other material might be selected) was poured into the tube. The portion of the liquid which came in contact with the glass solidified almost immediately, forming a cake at the bottom, and the specimen to be compressed was then inserted into the still unsolidified upper portion of the liquid, in such a position that it would be compressed in the desired direction, and the rest of the embedding material was then poured in quickly so that it would mingle with that already contained in the tube before this had completely solidified. When quite cold and solid, this upper portion, often more or less porous on account of the air bubbles which it contains, was pared away with a knife or filed away by means of a large, coarse, flat file, till the surface was level with the end of the tube. A few smart taps then removed the glass plate from the bottom of the tube thus filled, leaving a flat and polished surface.



When putting it in the press, it has been found best to place over each end of the tube a piece of stout brass plate. Upon the application of pressure the copper tube is first pressed into this plate at either end and a very firm and solid joint is made, the tube becoming converted into a box, from which nothing can possibly escape unless the tube itself is ruptured. The copper tube with its contents ready to be squeezed down in the press is shown in the accompanying figure. In some cases larger and heavier copper tubes of various sizes were employed.

Four different embedding materials were used in these experiments, namely, alum, sulphur, fusible metal, and paraffine wax. All these can be rendered fluid at comparatively low temperatures. Kick employed the two materials first mentioned and he also in some cases used shellac and in others stearine. Each of these substances has certain advantages. On the whole, alum and paraffine wax have been found to be the most suitable and in the present series of experiments have been used in the majority of cases.

Alum, if employed, can readily be removed at the conclusion of the experiment by placing the deformed tube in hot water on a water bath for a short time. But it has the disadvantage when used as an embedding material for limestones, that, whether in a state of fusion or solution, it attacks carbonate of lime to a noticeable extent. On soaking out the contents of the tube with warm water at the conclusion of the experiment, however, a very distinct effervescence always ensues and this is especially marked if the marble has been rendered at all pulverulent. The amount of calcite which is thus dissolved is not, however, great but it is quite sufficient to etch the surface and destroy the polish of the marble or the transparency of the calcite crystal employed in the experiment. In the case of all the more resistant minerals and rocks, this objection of course does not exist.

When sulphur, fusible metal, or paraffine wax is used, these are removed at the close of the experiment by simply heating the tube in a deep porcelain dish, over which a second smaller one is inverted on a sand bath or a water bath as the case may be.

In order to get some clear idea of the resistance to deformation offered by these several embedding materials under the experimental conditions, a series of experiments was carried out on the deformation of copper tubes or collars of the size usually employed, some of which were left empty while others were filled respectively with the several embedding materials referred to above.

The following table shows the results obtained in tabular form. The values are given in pounds and each represents the mean of two closely concurrent experiments.

	Maximum Load Sustained	Excess of Resistance Due to Contents of Tube
Empty copper tube.................	23,250	......
Copper tube filled with paraffine wax	23,800	550
Copper tube filled with fusible metal	29,925	6,675
Copper tube filled with sulphur.....	31,500	8,250
Copper tube filled with alum.......	34,450	11,200

It is seen in the first place that the copper tube when filled with paraffine wax offers but very little more resistance to deformation than does the empty tube. Under the conditions of the experiment

the paraffine wax develops but little internal friction and moves with comparative ease. With the other three materials the case is very different, a marked resistance being offered to deformation. This is greatest in the case of alum and least in the case of fusible metal. Subtracting the load required to deform the tube itself from that required to deform the tube filled with each substance respectively, it is found that the load required to deform the columns of the three materials in question (inclosed in the tubes under the conditions of the experiment) is that given in the last column of the table. These values calculated in pounds per square inch, using the area possessed by a cross-section of the columns of materials before deformation, which does not differ greatly from that possessed by the ends of the deformed masses, are given in the following table, together with the ratio of their respective strength or resistance which they offer to deformation, reduced to its simplest terms.

	Lbs. per Square Inch	Ratio of Strength
Paraffine wax	620.7	1.
Fusible metal	7533.9	12.13
Sulphur	9311.5	15.00
Alum	12641.1	20.36

In the case of a tube filled with paraffine wax, whenever the smallest fissure develops in the copper tube the inclosed paraffine passes out in the form of a thin, narrow ribbon and continues to issue as a long, graceful, curling band until the pressure is removed. When rupture takes place in a tube filled with alum the contents of the tube are not forced out until the crack has opened considerably, when the alum commences to fall out in a pulverulent condition. In the case of the fusible metal, on the other hand, the rupture of the inclosing tube does not lead to a discharge of the contents through the crack, but the copper tube peels off and the inclosed metal flattens down into a cake having a smooth, rounded surface. A striking fact noted in the case of tubes filled with sulphur is the continued sound of cracking which issues from the sulphur during deformation, a sound which resembles that produced when glass or any other brittle body is similarly compressed. At the conclusion of the experiment, however,

if the copper tube be sawn open the sulphur within is found to be to all appearances as hard and solid as any mass of sulphur could be, although in the mass, here and there, little surfaces can be detected which have a slight shimmer and which are evidently planes of slipping. The cohesion of the mineral along them, however, is to all appearances as great as elsewhere in the mass.

In connection with Kick's process there is one point of some importance to which attention does not seem to have been paid by those who have employed the process. This is the question as to whether, in carrying out the experiment, as the deformation of the cylinder goes forward, the pressure exerted on the specimen is conveyed to it entirely through the embedding material, or whether, in the latter stage of the compression, the specimen is actually nipped between the top and bottom of the tube or box which incloses it, that is to say, between the plates of the press, and is pressed upon directly by these without the intervention of any of the embedding material, or of a mere film which remains and which on account of its thinness exerts no influence.

Any experiment may be arranged so as to have the pressure exerted in either of the above ways, but no distinction seems to have been made between the two cases by former workers. As a matter of fact, however, very different results are obtained as one or other method of experimentation is adopted. If the specimen submitted to pressure continues throughout the experiment to lie entirely surrounded by the embedding material and is not pressed upon by the plates forming the ends of the tube, the value of the differential pressure to which it is subjected depends on the "stiffness" or viscosity of the embedding material, that is to say, on its internal friction. In the present state of our knowledge of the mathematics of plastic flow, it is impossible to calculate accurately the stresses set up in the inclosed specimen; although if movement is taking place in the embedding material the stresses are differential. When, however, the substance experimented upon offers great resistance to deformation, as for instance glass or porcelain, the differential stresses set up in any of the embedding materials hitherto employed are not, under the conditions of experimentation adopted, sufficiently powerful to bring about a deformation of the material. The alum, or whatever

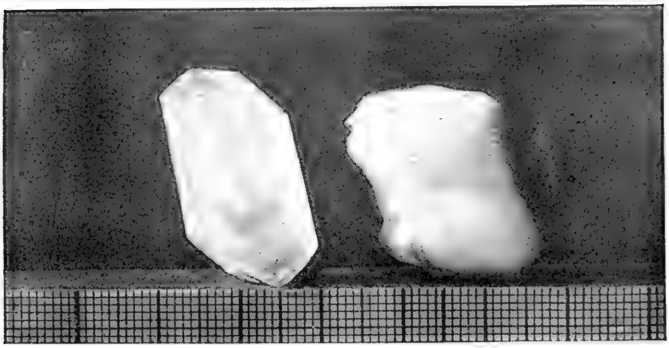
embedding material may be employed, flows around the specimen without producing any effect upon it. If an embedding material could be secured which under compression developed additional "stiffness," the required deformation of the substance might be secured, as when steel is used to inclose the specimen.

When, however, the length of the tube is so arranged that, after bulging has gone forward to a certain extent and the specimen inclosed in it has been submitted to the conditions above described, a point is reached when the top and bottom of the tube, backed by the press plates of the machine, come in contact with the specimen and commence to squeeze it between them, and a much more powerful vertical pressure is brought to bear upon the specimen. Under this, deformation is often produced in a specimen which cannot be obtained by the movements of the embedding material. It may happen, of course, that the vertical pressure thus exerted is relatively too great and the specimen breaks. This pressure, however, may be adjusted so as to yield excellent results.

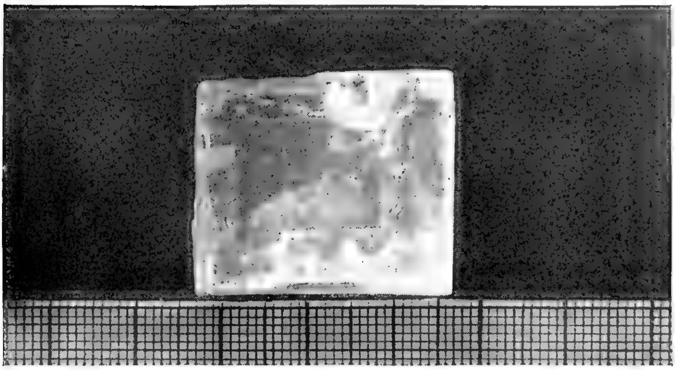
It seems clear that, under the experimental conditions which obtain in Kick's method, it is impossible to arrive at more than a general approximation in endeavoring to estimate the pressure to which the specimen is submitted. The pressure exerted by the machine is divided between the copper tube, the embedding material, and the specimen itself, and the resistance offered by each of these changes continually as the deformation proceeds. It is thus impossible properly to apportion the vertical pressure borne by each of the three elements, and when an attempt is made to go one step farther and estimate the lateral pressure exerted on the specimen by the material which incloses it, many additional and at present insuperable difficulties are encountered.

DEFORMATION OF CERTAIN MINERALS

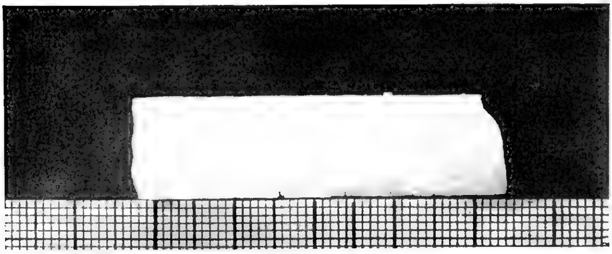
As preliminary to the study of the deformation of rocks, a series of experiments was made on the deformation of rock-making minerals under differential pressure. A number of minerals possessing a progressively greater hardness were selected, with the view to obtaining a series of results, beginning with minerals which are known to be readily susceptible of plastic deformation and passing to others



(*a*) Selenite crystal before and after compression



(*b*) Rock salt crystal before compression



(*c*) Same crystal as in (*b*)—after compression

whose capabilities in this direction are as yet unknown and then to still harder minerals which are considered to be perfectly brittle, so far as this property is known to be possessed by any body in perfection. The mineral species chosen were for the most part those constituting Mohs's Scale of Hardness, although certain others were also included in the list. The series was as follows:

Name of Mineral	Hardness Mohs's Scale	Name of Mineral	Hardness Mohs's Scale
Selenite	2	Limonite	5–6
Rock salt	2.5	Orthoclase	6
Iceland spar	3	Magnetite	5.5–6.5
Fluorite	4	Pyrite	6–6.5
Apatite	5	Quartz	7
Diopside	5.5	Garnet	6.5–7.5

The same body would undoubtedly give different values for plasticity if tested in different ways, just as the same body gives different values for the breaking point, according to whether the latter is measured by bending, tension, or impact.

Speaking generally, however, under ordinary conditions of temperature, hardness is a function of plasticity and minerals become less plastic as they become harder.

Selenite.—A clear transparent crystal from Ellsworth, Ohio, was selected. It was perfect in form, being bounded by the prismatic faces in combination with the clinopinacoids and clinodomes. The crystal measured 1.246 inches (31.6 mm.) in the direction of the vertical axis, and 0.618 inch (15.68 mm.) in the direction of the ortho-diagonal axis. This was placed in a copper tube 1.75 inches (44.45 mm.) high and otherwise of the standard size commonly employed in these experiments, namely, having an internal diameter of 1.062 ($1\frac{1}{16}$ inches, or 26.98 mm.), the walls of the tube being 0.125 ($\frac{1}{8}$ inch or 3.175 mm.) thick.

The crystal was placed in the tube on end, as shown in Plate I, Fig. *a*, so that it rested on the lower solid angle, the line of the intersection of the clinodomes being inclined at a considerable angle to the plane of the end of the inclosing tube. Paraffine wax was used as an embedding material, since alum, sulphur, or fusible metal melts at temperatures above that at which selenite loses its water. The paraffine wax, melting at a temperature below that of boiling water,

was poured around the selenite crystals until the tube was filled, the usual precautions already referred to being observed, and a brass plate was placed on either end, when it was inserted in the press and served as a top and bottom to the tube. The pressure being gradually raised, a large ring-shaped bulge gradually developed near one end of the copper tube, and eventually the metal began to tear open at one point on this bulge. The pressure was then taken off, the tube removed from the press, the paraffine melted away, and the selenite crystal obtained. The crystal was found to have undergone a very marked deformation.

In order to obtain further deformation, the crystal was then placed in the same position in another tube, having the same diameter as that formerly employed but only 1.5 inches (38.1 mm.) high, and this, after the residual space had been filled with paraffine, was compressed in the same manner as before. In this shorter tube a further deformation of the selenite was secured. The maximum load employed was 24,000 pounds (10,872 kilos), and the total time during which deformation was actually going forward was 70 minutes. The selenite crystal, after removal from the tube, is shown in Fig. *a*, Plate I, there being placed beside it another crystal of the size and shape which it originally possessed. It will be seen that the acute solid angles of the monoclinic prism have been turned back by movement along a plane coinciding approximately in direction with an orthodome, while both ends have also been bulged out laterally and the whole crystal has also been slightly curved. There are no traces of fracture, tearing, or cleavage, but the surface of the crystal—more especially in those parts which are most deformed—is minutely wrinkled. The extremities of the crystal, where the deformation is most intense, have for the most part lost their transparency and are now translucent.

In the case of selenite, therefore, deformation under differential pressure can be produced readily and at comparatively low pressures. It is certain that in the case of the selenite crystal in question, a much greater deformation might have been secured by placing the crystal in successively shorter and wider copper tubes as each showed signs of rupture, and thus flattening it out by stages.

Rock salt.—A large cleavage cube of clear transparent rock salt

was taken. This measured 1.378 inches $\times$ 1.18 inches $\times$ 1.38 to 1.389 inches (35 mm. $\times$ 30.05 mm. $\times$ 35.05 to 35.3 mm.). It was inclosed in paraffine wax in a copper tube in the usual way. This was squeezed down until it showed signs of rupture when the salt crystal, now considerably flattened, was removed and placed in paraffine in another shorter but wider tube, which was in its turn squeezed down until rupture threatened, when the crystal was removed to a third and still wider piece of copper tube, in which the deformation was completed, the maximum load employed being 157,000 pounds.

The salt when removed was found to have the form of a continuous flat cake, nearly square in section. It now measured 0.56 inch (14.2 mm.) in thickness and was 2.215 inches to 2.25 inches (53.97 mm. to 57.15 mm.) by 2 inches to 2.125 inches (50.8 to 53.975 mm.) in diameter. Photographs of the crystal as it appeared before and after deformation are shown in Plate I, Figs. *b* and *c*. Although a solid mass, quite firm and hard, it had developed a series of fissures extending from both the lower and upper surfaces into the mass, these being wedge shaped in form and following the direction of the faces of the cube, i.e., running parallel to the longer sides of the flattened crystal. These fissures did not pass completely through the crystal from top to bottom, but often penetrated into it deeply. Neither were they continuous from side to side, but were interrupted and crossed each other at right angles. They were not seen on the narrow edges of the mass.

The deformed crystal of salt was brightly translucent but not actually transparent, and the sides of the flattened crystal were in several places beautifully curved. The remarkable plasticity of the salt not only is shown by the manner in which the crystal was flattened out, but is seen in a striking way where the cube, having been carried against the sharp incurving edge of the spreading end of the tube in one place, took an impression of the latter in the form of a deep, sharp-angled, and smooth-faced groove crossing the corner of the salt cube, the impression being as sharp as if it had been taken in wax.

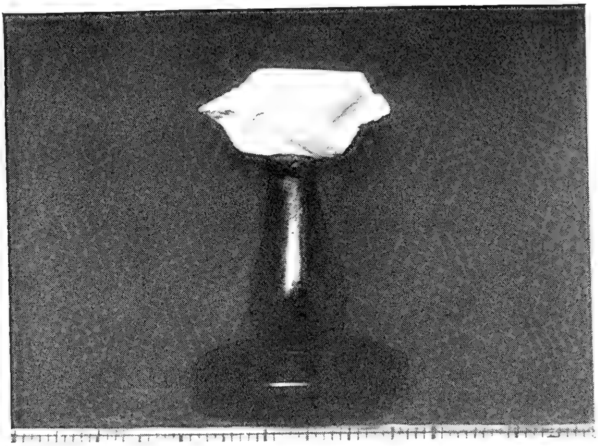
In the present case it was found inadvisable to carry the deformation of the salt any farther, since the little fissures mentioned above having once formed, the downward pressure forced the paraffine into them, and thus tended to divide up the salt crystal by a series of

paraffine wedges driven into it. Even in this case, the crystal would develop a filigree pattern; but if the conditions of the experiment be slightly altered so as to prevent the formation of the wedges of paraffine, it is believed that a salt crystal, on account of its great plasticity, might be flattened out to almost any required extent and might be molded into any desired form.

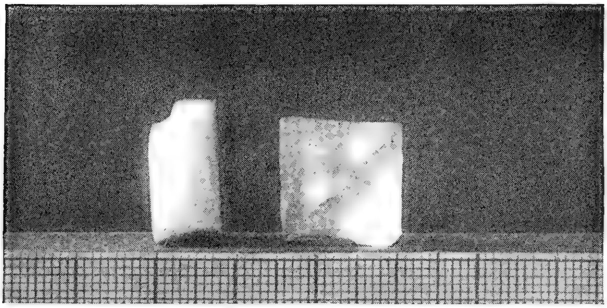
Iceland spar.—Since in considering the deformation of marble the effect of differential pressure on the constituent calcite grains is described, it is unnecessary here to repeat these descriptions. It may, however, be of interest to refer to a single experiment on the deformation of a large cleavage fragment of Iceland spar.

In this a cleavage rhombohedron of Iceland spar, measuring 0.73 inch (18.54 mm.) between the acute angles of the rhombohedron, was embedded in alum in a copper tube of the usual type, having a height of 1.25 inches (31.75 mm.), and a wall thickness of 0.125 inch (3.175 mm.), the tube being closed by a thick plate of cast iron placed against one end and a plate of machinery steel placed against the other, the rhombohedron being so set that its acute edges would come against the metal plates at either end as the deformation progressed. The tube was then squeezed down to a height of 0.473 inch (12.01 mm.), under a load of 83,000 pounds. On dissolving away the alum it was found that the calcite rhombohedron had been pressed into the metal plates at either end, leaving a faint but clearly perceptible impression on the machinery steel at one end and a somewhat more distinct one in the cast iron at the other. Neither of these, however, was so distinct as those produced by the fluorite (see below). The edges of the calcite which produced the indentations remained quite sharp and showed no granulation, but the crystal under the pressure has been converted into a perfect twin crystal, the plane of twinning being at right angles to the direction of maximum pressure (see Plate II, Fig. *a*).

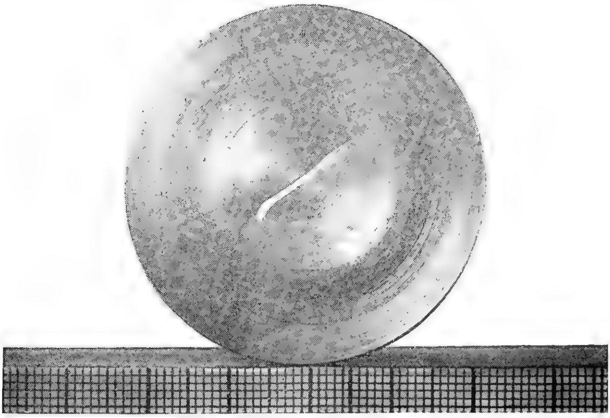
Fluorite.—Passing to the next higher member of Mohs's Scale of Hardness, the action of differential pressure on fluorite was investigated. Five experiments were made with this mineral. For the first, a group of twinned fluorite crystals, green in color and consisting of three interpenetrating cubes from Weardale, Durham (England), was selected, the largest of these crystals being 0.82 inch (20.8 mm.)



(*a*) Twin of calcite produced by compression



(*b*) Fluorite crystal before and after compression



(*c*) Nickel steel disk penetrated by the edge of a crystal of fluorite

in diameter. This was placed in a copper tube, 1 inch (25.4 mm.) high and otherwise of the same dimensions as those usually employed, namely 1.0625 inches (26.98 mm.) in internal diameter, and having a wall 0.125 inch (3.175 mm.) thick. Melted alum was used as an embedding material and a brass plate was used to form the top and bottom of the tube. The whole was then placed in the press and squeezed down until the tube was reduced to 0.75 inch (19.05 mm.) in height. When, this, having assumed a symmetrical bulge, commenced to develop minute fissures in its most distended portion, the experiment was brought to a close. The time occupied in the deformation was 50 minutes, the pressure being gradually raised until it reached a load of 42,500 pounds. On dissolving away the alum, the group of fluorite crystals was obtained as a firm coherent mass, but the deformation had been so great that while portions of two cubes could be recognized, the rest of these two cubes and the third cube had been so welded together into a lump that it was impossible to distinguish them or to ascertain which part of the mass they represented. The green color of the original mineral had disappeared except in one or two spots, and its place had been taken by a pale violet tint, and the mineral, which was originally transparent to translucent, had become practically opaque.

A thin section of the deformed mass was then prepared, which, when examined under the microscope, showed that the fluorite was still clear and transparent, except along a few lines which traversed the slide in sinuous curves. Here the mineral presented a turbid appearance. The three individuals composing the mass were seen to be traversed by their respective cleavage lines, evidently developed in grinding the section, which made it possible to determine their boundaries in a general way. Each cleavage line was seen to follow a straight course, until it approached the turbid lines above mentioned, when it bent with a sharp curve or sudden twist; the crystal along these lines where the movement was greatest being broken into a mass of minute grains, still, however, firmly coherent. When examined between crossed Nicols the fluorite was seen to remain perfectly isotropic, except along the lines of most intense movement and granulation, where it can frequently be seen to be distinctly doubly refracting.

It is thus evident that the mineral fluorite is plastic to a marked degree. It may be bent and twisted without any signs of disruption and it is only along certain lines of very intense movement that the mineral breaking develops a cataclastic structure, just as marble does in places when deformed under low differential pressures. The little broken grains of fluorite thus produced, however, as in the case of the marble, remain firmly coherent, and it is highly probable that, as in the case of marble, if the deformation were carried on under much higher pressures or at a higher temperature, fluorite could be deformed without any fracture or the development of any cataclastic structure whatsoever.

While, however, the plasticity of the mineral is remarkable, its resistance to movement and the force required to bring about its deformation appear to be considerably greater than in the case of calcite, and it was observed that an angle of one of the fluorite crystals which cleared itself from the alum and came into contact with the brass plate at one end of the tube made a distinct triangular depression in it.

Several other experiments with a perfect cleavage octahedron of fluorite from Westmoreland, Cheshire Co., New Hampshire, carried out under identical conditions, resulted in the flattening of the rhombohedron, the movement being of the nature of a plastic flow, except possibly where here and there a few little opaque white lines indicated the development of a minute cataclastic structure. In these experiments also the fluorite showed the same stiffness or resistance to deformation, which was seen not only in the very high pressure required to deform it, but also in the fact that as the copper tube was squeezed down and the alum flowed away from above and below it, leaving the mineral in contact with the brass plates at either end, the octahedral faces of the mineral, where they came upon the brass plate below, sank into it, leaving a well-marked depression, while the two octahedral edges bounding the face in contact with the upper brass plate, which was 0.075 inch (1.9 mm.) thick, cut completely through it, leaving a wide rent, and having passed through this plate, forced their way into a second brass plate behind it.

Another experiment employing much higher pressures was then made by taking an octahedron of fluorite, similar to that employed

in the last experiment, and inclosing it in alum in a piece of thicker copper tube. This tube was 0.75 inch (19.05 mm.) high, and made of metal 0.187 inch (4.65 mm.) thick. The octahedron was set in the alum so that it rested on an edge. For the ends of the tube, instead of brass plates, plates of steel were used. That at the bottom of the tube was made of machine steel one inch (25.4 mm.) thick, and that at the top was a plate of nickel armor steel 0.063 inch (1.6 mm.) thick. The tube was slowly squeezed down to a height of 0.384 inch (9.75 mm.). This occupied 30 minutes, the load finally reaching 112,000 pounds (50,804 kilos). The fluorite octahedron was found to have been squeezed into a nearly square tabular mass (Plate II, Fig. *b*) measuring about three-quarters of an inch across, the movements being of the same nature as those described in the last experiment. Crossing the top and bottom of this mass diagonally were two faint ridges representing a survival of the edges of the octahedron. These by the pressure had been brought into contact with the steel plates at either end of the tube and had actually embedded themselves in the latter, the upper and sharper edge sinking into the nickel steel, leaving a deep, well-marked depression in the steel along its whole length (Plate II, Fig. *c*), and at the same time distinctly bending the plate. The lower edge, which was blunter, left a similar depression in the machine steel below. These edges of the fluorite crystal, although having in this way forced themselves into the steel, showed no signs of breaking or granulation, but were intact. It would without doubt be possible, by changing the conditions of the experiment somewhat, to force a crystal of fluorite completely through a piece of steel armor plate.

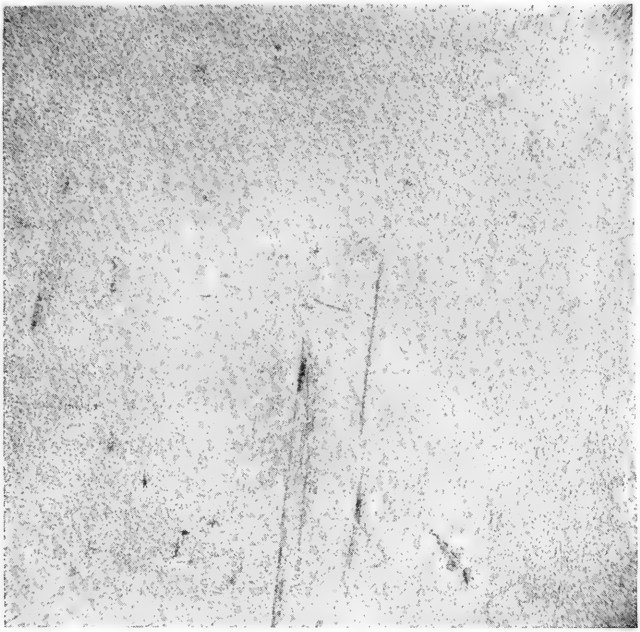
As in the other experiments, the color as well as the form of the mineral was found to have been altered by the pressure. Two of the opposite solid angles of the octahedron still retained a green color though much paler than before, but the rest of the flattened crystal, including the edges which had embedded themselves in the steel, that is to say, that portion of the mineral which had been submitted to the most intense pressure, was found to have assumed a distinct violet or purple color.

Another experiment, in which paraffine wax was used instead of alum as an embedding material, showed that with this medium a

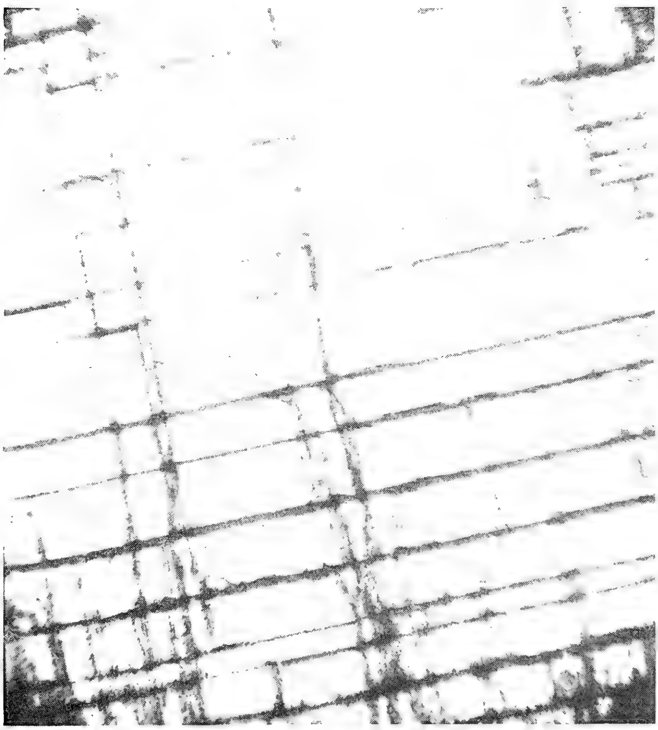
similar distortion of the fluorite was produced while the green color of the original mineral became much paler. The change in color of the fluorite which, as noted above, was produced in every instance by the pressure is a very curious phenomenon. In three of the experiments the change consisted in the substitution of a much paler tint of green for the deeper green color which the mineral possessed originally. In the other two cases, where the deformation had been if anything more intense, the original green color actually changed to pale purple or violet, a color which is often possessed by the fluorite from Derbyshire and elsewhere. The reason for this change is unknown and will probably remain so until the nature of the fugitive colors displayed by this mineral have been discovered. It was at first thought that the change in question might have been brought about by the heat of the molten alum in which the mineral was embedded and that it might thus have been induced before the pressure had been applied. Crystals of the fluorite from both localities were accordingly taken and embedded in molten alum in the usual way, but it was found on removing the alum by solution that no change in color whatsoever had resulted from this treatment. The change in color therefore must be due solely to the action of pressure.

Apatite.—A small crystal of opaque greenish apatite from one of the Canadian localities, probably in Ottawa County, Quebec, measuring a little less than 1.25 inches (31.75 mm.) in height, and about 0.5 inch (12.7 mm.) in diameter, was selected. The crystal showed the usual prismatic and pyramidal faces seen in the specimens from this district, as well as small basal planes. It was placed, resting on one of the pyramidal faces, in a copper tube of the same dimensions as that employed in the last experiment, but 1.25 inches (31.75 mm.) high. The tube was then filled up with molten alum in the usual way and brass plates were placed at either end. The whole was then slowly squeezed down until the tube showed signs of rupture, the time occupied by the deformation being 55 minutes and the maximum load being 43,000 pounds (19,405 kilos).

On dissolving away the alum the apatite crystal was found to have been crushed to a coarse powder at either end. The central part—representing about one-half of the original crystal—however, remained as a solid mass, and showed portions of the six prismatic faces. Crossing



(*a*) Microphotograph of a thin section of a diopside crystal before compression. Between crossed Nicols



(*b*) Microphotograph of same, after compression. Showing the development by the pressure of polysynthetic twin lamellae

this remnant of the crystal approximately parallel to a pyramidal face, and thus in a direction approximately at right angles to the direction of pressure, some half-dozen planes could be seen along which movement of the nature of a minute faulting had taken place. The mineral, however, was firmly coherent where traversed by these planes, indicating that apatite under the experimental conditions, although breaking along certain lines, was firmly welded together again by the pressure and was thus slightly plastic. A further evidence of plasticity is afforded by the fact that one of the prismatic faces shows a slight but distinct bending or curving.

The evidence afforded by the experiment, therefore, shows that while apatite is very much more brittle than the softer minerals of the series, it nevertheless possesses the property of plasticity in a slight degree at least, a conclusion which is confirmed by the occasional discovery of apatite crystals which are distinctly curved or bent in the highly contorted crystalline limestones and associated rocks of Laurentian age in the Ottawa district. That the mineral is, however, but slightly plastic even under the conditions of very great pressure which obtain during the contortion of the limestones above mentioned, is shown by the fact that the curved crystals to which reference has been made are always found to be broken when the bending becomes very pronounced.

Diopside.—A number of clear crystals of pale green diopside from De Kalb, New York, were secured, and from these two were selected. These, together with an octahedron of magnetite from Mineville, New York, were embedded in alum, inclosed in a copper tube, and submitted to pressure in the usual manner adopted in Kick's method. The copper tube was 0.877 inch (22.29 mm.) high, but otherwise of the same dimensions as that employed in the case of apatite—the experiment being carried out in the same manner. The diopside crystals were quite transparent and showed both pinacoids, the prisms, two sets of domes, and one set of pyramidal faces. One of these crystals was placed in the tube so as to lie upon its orthopinacoid, the direction of the pressure being consequently at right angles to this face; while the other was placed so that the pressure would be exerted upon it in a direction as nearly as possible at right angles to the base. The pressure was continued until the copper tube commenced to show

signs of rupture, the time occupied by the experiment being about one hour, and the load finally rising to 48,000 pounds (21,773 kilos). On removing the test from the press, it was found that the end of one crystal of pyroxene was protruding slightly from the alum and had sunk into the brass plate, leaving a distinct impression in it; and, on dissolving away the alum, it was found that both pyroxenes displayed a twinning parallel to the base which had been developed in them by the pressure; this being strikingly seen in the case of the crystal which was compressed approximately in a vertical direction. The twinning in the case of this crystal appeared as a series of little parallel lines crossing the lateral faces in the direction of the base, and in appearance resembling closely the basal parting so frequently seen in pyroxenes which occur in the limestones of the Grenville series and other rocks which have been submitted to great compressive stresses.

A section was then cut through this crystal in a vertical direction. Under the microscope, between crossed Nicols, this was found to be so orientated as to intersect the crystal in a direction between the orthopinacoid and a prismatic face. The prismatic cleavages were well seen and a second set of interrupted cleavages crossed these at right angles or nearly so, being parallel to the base. Parallel to these latter was a beautiful series of clear, sharply defined, polysynthetic twin lamellae, which had been developed by the pressure. The section was 14 millimeters wide, and in this width displayed 140 twin lamellae, each of which was wide enough to show clearly its individual character, the series being spaced at nearly equal distances across the crystal. Their appearance under the microscope is shown in Plate III, Fig. *b*, while Plate III, Fig. *a*, shows the apearance of a section of the original pyroxene. Apart from the twin lamellae, the mineral shows a slightly undulating extinction, and the section is crossed in one or two places by narrow lines of granulated material, along which, under the pressure, the mineral has broken with the development of a cataclastic structure. A study of the section shows that probably the twinning was first developed and that the mineral under further pressure broke along certain lines. The partial loss of transparency observed in the deformed crystal is largely due to the development of similar lines of broken material, especially at the

ends of the specimens where this loss of transparency is most pronounced.

It is thus evident that under the differential pressure the diopside crystals became slightly twisted, and then, as the pressure increased, changed their shape somewhat by the development of a series of polysynthetic twin lamellae, finally breaking along certain lines, with the development of cataclastic structure. In a paper published in 1886, Mugge[1] describes some experiments which he carried out on the behavior of diopside under pressure. He inclosed clear and untwinned crystals of this mineral in lead and then squeezed the mass down by means of a powerful screw press. In some cases he found that the mineral was reduced to a powder, and in other cases the crystal survived, but, even after repeated trials, he was unable to induce any twinning in it. In some few cases, in the partially crushed crystals, he found what was apparently a twinning parallel to the base. He states, however, that he could very rarely get a section of the twinned material so thin and with the lamellae so broad that the individual lamellae showed their own optical orientation, their existence being indicated merely by the fact that between crossed Nicols the extinction was never complete. It is possible, however, as above described, by employing Kick's process, to obtain in diopside a perfect twinning, in which clear, well-defined lamellae extend through the whole individual and are identical in character with those seen in the twinned diopsides found in crystalline limestones which have been subjected to orogenic movements.

Limonite.—A cube, pseudomorph after pyrite, from a locality in Virginia was selected. It was treated in precisely the same manner and in a tube of the same thickness as in the case of the apatite and diopside. On dissolving away the alum, the cube of limonite was not found to present any distinct evidence of plastic flow. Its lower surface was intact except for the presence of a minute crack. The upper surface was traversed by many minute open fissures which crossed one another, giving rise to a rudely rectangular pattern. Each rectangle formed the base of a wedge of the material which was driven downward, causing the sides of the cube to slant outward.

[1] "Ueber künstliche Zwillingsbildung durch Druck am Antimon, Wismuth und Diopsid," *Neues Jahrbuch für Mineralogie* (1886), I, 183.

It is evident in this case that while there may have been some slight plastic deformation in portions of the cube, the movement has been essentially one which has taken place along planes of fracture.

Orthoclase.—The crystals used in this experiment were from Good Springs, Lincoln County, Nevada. They were of simple form and very symmetrical development, being bounded by the clinopinacoids, the basal faces, and the unit prisms.

Three of the crystals were placed together in the same copper tube, one lying on a clinopinacoid, one on a prismatic face, and one on its basal plane. The experiment occupied one hour and forty-five minutes. Alum was used as the embedding material and the maximum load—which was of course that reached at the conclusion of the experiment—was 195,000 pounds (88,455 kilos). As the compression slowly proceeded, faint cracking sounds were frequently heard from the interior of the tube. On removing the brass plate, the outlines of the crystals could be seen in the alum at either end. At one end they were for the most part still covered by a thin film of alum, while at the other end they had been forced into the brass plate, deeply indenting it; while one of the crystals, in which a sharp edge came against the brass plate, had forced its way through this plate, tearing it completely open. These portions of the crystal in contact with the brass plates showed no signs of fracture. On dissolving away the alum, however, all three crystals were found to have been much crushed in places.

The crystal which lay upon the prismatic face still held together but was traversed by several little fissures which had their courses chiefly parallel to the base and to the clinopinacoid, that is, in the direction of the normal cleavage of the mineral. They did not, however, invariably follow these planes, but in some cases ran irregularly across the crystal. The individual which lay upon its clinopinacoid had crumbled to pieces. The largest of these pieces showed little cracks parallel to the base and to the clinopinacoid and others running in the direction of the orthopinacoid. The crystal which rested upon its basal plane was reduced to a mass of little fragments without definite form.

Two thin sections were prepared from the first and second of the crystals respectively, in order to ascertain whether any further evi-

dence as to the character of the movement which had taken place could be obtained by a microscopic study of the crushed mineral. The sections in both cases were cut parallel to the orthopinacoid, while, for purposes of comparison, a third section running in the same direction was prepared from one of the original uncrushed crystals. Under the microscope the crystals which had been subjected to compression were seen to be traversed by a number of minute cracks, and also showed in the much-crushed portions faint strain shadows, when examined between crossed Nicols. It is evident, therefore, that under the conditions of the experiment, the orthoclase, while probably displaying a very slight plastic movement of the nature of twisting, as shown by the slightly uneven extinction produced by the pressure, moves almost entirely by fracture and granulation. This agrees with the deportment of orthoclase as observed in highly deformed rocks in the earth's crust, the mineral in these rocks being usually granulated or recrystallized under conditions of differential pressure.

Magnetite.—A perfectly symmetrical octahedron of this species from Mineville, New York, was, as mentioned above, embedded in alum and submitted to pressure, with the diopside crystals whose behavior has already been described. On dissolving the alum, the magnetite was found to have been broken to pieces, the fragments having the form of little plates which had separated from the crystal parallel to the octahedral faces.

Pyrite.—The pyrite employed was from the Saratoga Mine, Gilpin County, Colorado. The fragment selected had the form of a half cube, showing the crystal faces, with a surface of fracture on one side. The specimen, with the edge of the cube upward, was embedded in alum in a copper tube with a brass plate at either end. Pressure was then applied, the deformation of the tube occupying 17 minutes, and the maximum load attained being 43,000 pounds (19,404 kilos). No sounds whatever issued from the tube as the deformation went forward. On removing the highly bulged tube from the press, it was found that the edge of the pyrite crystal, referred to above, had passed completely through the brass plate and had cut into the iron head plate of the press, the edge, however, remaining practically intact. On dissolving away the alum, it was found that

the lower portion of the crystal, still embedded in the alum, had been much crushed, the original crystal being now represented by one large fragment and a considerable quantity of fine powder. The pyrite, therefore, was crushed without showing any trace of plastic deformation.

Quartz.—A clear transparent individual of rock crystal from Hot Springs, Arkansas, was selected. It was embedded in alum in the usual way in a copper tube. The crystal was placed in a somewhat slanting position in the tube, so that it stood approximately on a pyramidal face. The pressure was raised gradually and the load used was just sufficient to start and maintain a very slow bulging of the tube. The pressure was continued for an hour and twenty minutes, by which time the height of the tube had been reduced to 1.37 inches (34.8 mm.), the maximum load employed being 34,000 pounds (19,404 kilos). Once only during the deformation was a faint cracking sound heard in the tube. On removing the alum, the quartz crystal was found to be still coherent with the exception of a few little fragments which had broken off from one end. The crystal, however, was traversed by a large number of cracks following directions approximately parallel to the rhombohedral faces, many of them not passing completely through the crystal, but running only a certain distance and being intersected by others crossing them. It is known that quartz when heated and suddenly cooled develops a tendency to rhombohedral cleavage; but it is also true that when a rigid or an imperfectly plastic body is submitted to pressure it tends to shear along planes which cross one another at an angle approximating to 90°. Whether in this case a tendency to movement along rhombohedral planes was developed, or whether the movement is one quite independent of crystallographic considerations, is uncertain. There was certainly, however, no indication of plastic flow.

Garnet.—The last mineral examined, being also the hardest, was garnet, a perfect rhombic dodecahedron of almandine from Bödo, Norway, being selected. It was embedded in alum in the usual manner, the whole being inclosed in a copper tube. The deformation of the tube occupied 50 minutes and the maximum load required was 175,000 pounds (79,383 kilos). A slight cracking sound was emitted at times as the experiment was going forward. On dissolving the

alum, the greater part of the crystal was found to have been reduced to a fine powder. There were a few larger fragments surviving but these showed no signs of distortion. The fragments when examined between crossed Nicols were found to be perfectly isotropic. The garnet, in fact, had been crushed and displayed no traces of plastic deformation.

DEFORMATION OF ROCKS

Seeing, as has been shown, Kick's method is not adapted for the development of plastic deformation in materials which are very hard, the rocks selected for examination were chiefly of the softer kinds, marbles, limestones, and dolomites of different varieties. The harder rocks were, however, represented by a typical granite. In these experiments columns of the rock were usually employed. These were 1.575 inches (4 cm.) long and usually 0.787 inch (2 cm.) in diameter, with a smooth and generally a polished surface. The copper tubes employed were somewhat larger than the column so that the alum might completely inclose the latter, and had an internal diameter of 1.06 inches (27 mm.) and a wall thickness of 0.125 inch (3.175 mm.). In some cases, as will be mentioned, cubes, prisms, and spheres of the rock were also deformed.

A. MARBLE: CARRARA, ITALY

This is the same white statuary marble which was employed in a former investigation and described in a former paper.[1] In the case of the large spheres, however, a somewhat commoner variety from the same locality was employed, since blocks of the statuary marble of requisite size for the preparation of these spheres could not be obtained.

1. COLUMNS

Columns of the marble were first used and the effect of various kinds of embedding material was studied.

(*a*) *Deformation with paraffine as an embedding material.*—The maximum load required for deformation of the tube with its inclosed

[1] F. D. Adams and E. G. Coker, "An Investigation into the Elastic Constants of Rocks, More Especially with Reference to Cubic Compressibility," *Carnegie Institution of Washington, Publication No. 46* (1906), 26.

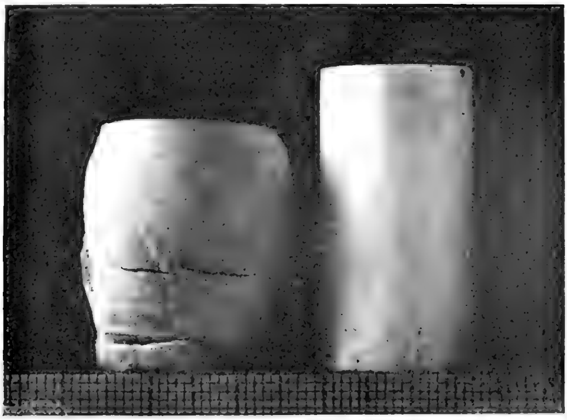
marble and embedding material in these experiments was 30,500 pounds.

The column after deformation, when removed from the paraffine, displays a very characteristic shape, and one which is quite different from that shown by the rock when deformed in alum. The movement set up in the column commences at one end and gradually extends toward the other end of the column, not however as a general rule reaching this before the experiment has to be brought to a close on account of the impending rupture of the copper tube.

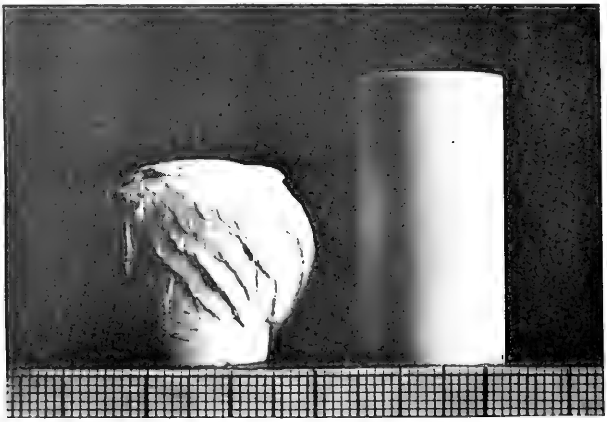
This movement results in the development of a symmetrical enlargement of that part of the column affected, the greatest diameter being a short distance from the end of the column. The deformed portion of the column thus swells out into a more and more pronounced bell-shaped form, which fades away into the unaffected portion of the column, which latter retains not only its form but also the original polish of the surface.

Crossing the smooth, bell-shaped surface, in that portion of the column in which movement has taken place, are certain faint lines which when the deformation is slight are just barely perceptible, but which become more pronounced as the deformation increases. These lines, which are uniformly spaced, or nearly so, are due to a very slight displacement along their course and are, as is well known, developed when any solid body is strained above its elastic limit. They are known as Cooper's or sometimes as Luder's lines. As seen on any one part of the lateral surface of the cylinder, they are arranged in two series which cross one another at an angle which, as nearly as it can be measured by an application goniometer, is 72 degrees. That is to say, each line makes with the vertical, which is the direction in which the pressure is applied, an angle of 36°. Along this multitude of intersecting planes, in the early stage of deformation, movement takes place with approximate uniformity, and as a result the cylinder slowly shortens, widening at the same time as described into a symmetrical, bell-shaped form which tapers down into the undeformed portion of the cylinder.

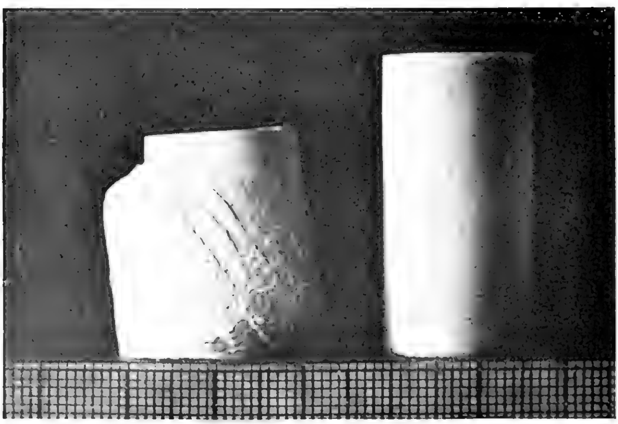
As the deformation goes forward and becomes more pronounced the movement, while still taking place simultaneously along a great number of these planes, becomes more pronounced along certain of



(*a*) Column of Carrara marble before and after deformation—using paraffin wax as an embedding material



(*b*) Column of Carrara marble before and after deformation, using alum as an embedding material



(*c*) Column of Carrara marble before and after deformation, using alum as an embedding material

them, so that, with the lateral expansion or bulging of the cylinder, there is combined a tendency for a portion of the cylinder to move more rapidly along some one plane, developing a specially pronounced shear in this direction. No rupture ensues, but the more pronounced movement in this direction is evident from the form of the distorted cylinder. This is shown in Plate IV, Fig. *a*, where the traces of such planes bound a V-shaped projection on the front of the deformed column. On the base or end face of the bulging portion of the cylinder, the lines above described are not seen, unless they be represented by a series of little, somewhat irregular radial fissures noticed where the deformation is very pronounced.

One noteworthy fact observed in every case where a cylinder of the marble was deformed in paraffine is that the column on removal of the paraffine is found to be cracked or fractured transversely, that is, in a direction at right angles to the axis of pressure. This is seen in Plate IV, Fig. *a*, where two of such fractures parallel to one another were developed in the same cylinder. The surface of such a fracture plane is approximately flat but not absolutely smooth or polished, and in partially deformed cylinders it frequently occurs just about the line between the deformed and undeformed portion. The same planes of transverse fracture are developed, upon the relief of pressure, in very strong fine-grained limestones when they are deformed in steel tubes. It is apparently connected with the elastic expansion of the rock on the removal of stress.

The invariable presence of this transverse fracture makes it impossible to determine the strength of the deformed column in compression. While probably not so strong as the original marble, it is still firmly coherent and hard, withstanding a sharp blow without breaking. When the deformation is pushed to an extreme, in addition to the Luder's lines, a series of faint, slightly wavy lines, running in a horizontal direction across the column and hence in a direction at right angles to the pressure, is developed.

When a section of the deformed marble is examined under the microscope, the decrease in transparency of the rock as compared with the original marble at once arrests the attention. This, on close examination, is seen to be due to the development of an immense number of twinning lamellae in the constituent calcite grains, often

in two or more sets crossing one another. These lamellae are very narrow, often taxing the power of the microscope to resolve them, but there is scarcely a calcite individual in the slide which is not crowded with them. It is thus evident that every individual grain in the rock has been affected by the movement and has changed its shape to a greater or less extent. When, however, the marble has been very highly deformed, movement is also seen to have taken place by granulation of the rock. In any single section the granulation has a tendency to develop along two intersecting planes, but as the deformation becomes more pronounced, the two series tend to converge and follow a more nearly horizontal course, and a single little line of granulation can often be seen to follow a minutely zigzag line running alternately in the direction of one series and then of the other, the resultant course of the line being transverse to the column and at right angles to the pressure. In this way the deformed column tends to break transversely with a slightly uneven surface, as mentioned above. It is to be noted that the marble does not show any tendency to develop a cleavage except in a direction at right angles to the pressure.

b) *Deformation with fusible metal as an embedding material.*—A column of the marble was then deformed, using fusible metal as an embedding material. The column and tube were of the same dimensions as in the experiments just described and the load required for maximum deformation was 35,000 lbs. The surface of the marble after deformation was found to be lusterless and displayed none of the intersecting lines seen when the rock is deformed in paraffine. The deformed column resembled in shape certain of the columns deformed in paraffine, but the rock itself was converted into a uniform chalky looking material which was much more friable than the marble deformed in paraffine. The mass was soaked in balsam, and thin sections were prepared from it. These, when examined under the microscope, were found to present essentially the same characters as in the case of the marble deformed in paraffine and just described. The twinning, however, was less marked and the granulation more pronounced.

c) *Deformation with sulphur as an embedding material.*—A column of marble of the same dimensions as before was then deformed

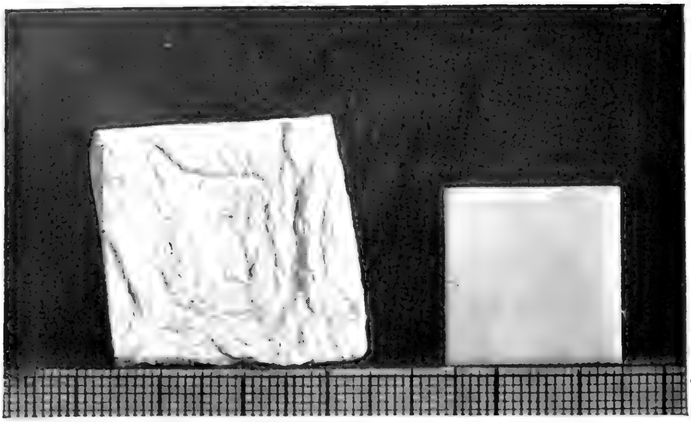
in a copper tube, also of the same dimensions as that employed in the experiments just described, but with sulphur as an embedding material. The deformation required a load of 37,500 lbs. (17,000 kilos). When the sulphur was melted away from the marble, the deformed column was found to be hard and solid, and to have been reduced in height from 1.561 inches (39.65 mm.) to 1.145 inches (29.09 mm.), a shortening of about 27 per cent. Its shape was striking, for one half of the column had sheared down over the other half, the plane of shearing making an angle of 36° with the vertical, which was the direction of pressure, and an angle of 54° with the horizontal, which is the same angle as that observed in the case of the lines traversing the surface of the marble when deformed in paraffine. This shearing movement did not take place on a single plane, but on a series of planes parallel to one another, or nearly so, and close together, giving rise to exactly the same structure as that seen in the "sheeted veins" or "shear strips" of many mining districts, as for instance at Cripple Creek. It is an excellent example of a distributed fault. The second series of lines seen in the paraffine experiments are here faintly indicated in a few places. There are no signs of rupture to be seen in the deformed column. The surface is nearly smooth, its only unevennesses being due to slight projections along the line of some of the planes constituting the distributed fault.

A series of thin sections was prepared, passing through the deformed column in a vertical direction. Under the microscope it is seen that there has been a slight movement throughout the rock, as indicated by the presence of a fine polysynthetic twinning in almost every calcite grain. This, however, has not been sufficient noticeably to flatten the grains in any direction. The chief movement is along the planes of shearing and is accompanied by a minute granulation, with the development, in many cases, of a microscopic breccia along the planes in question. The lines of shearing as seen under the microscope are not perfectly straight, but while maintaining a generally uniform course often have numerous little anastomosing branch fissures running parallel to them and occasionally crossing from one shear plane to another. The shearing thus takes place along a strip of the rock instead of in a single plane, and this strip is thus filled with a minute calcite breccia. The appearance under the

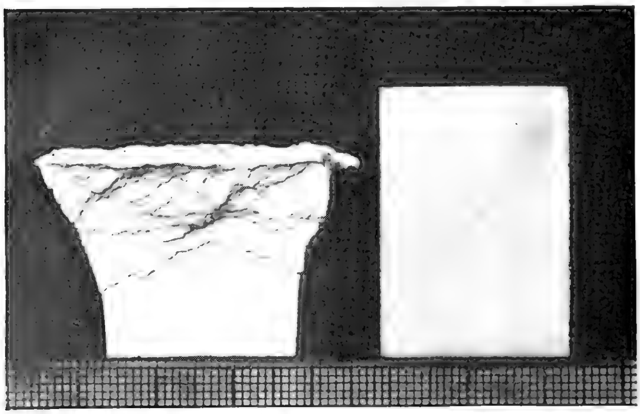
microscope is exactly that presented on a large scale by many fault planes.

d) *Deformation with alum as an embedding material.*—As has been shown, alum is much more resistant to deformation than either paraffine, fusible metal, or sulphur. A series of marble columns was accordingly deformed by Kick's method, employing alum as an embedding material. These were of the same dimensions as before, as were also the copper tubes employed. The maximum loads employed in the several experiments were from 35,000 lbs. to 41,500 lbs. The time of deformation was from 15 to 45 minutes. The shape presented by the deformed marble column is remarkable. The column for some distance from either end, in the earlier stages of deformation, remains intact, and these terminal portions are forced toward one another and into the middle portion of the column, which bulges outward, not however with a smooth symmetrical outline but with the development of a curious leafy form, which, when looked down upon from the end of the column, bears a resemblance to an artichoke. The leaves which wrap closely around the central stalk have well-developed, wedge-shaped points or terminations and occur in great numbers. They, however, are not arranged in regular series but each individual leaf has the appearance of overlapping others which lie beneath it. One of these curious forms is shown in Plate IV, Fig. *b*, with a column of marble of the original dimensions placed beside it.

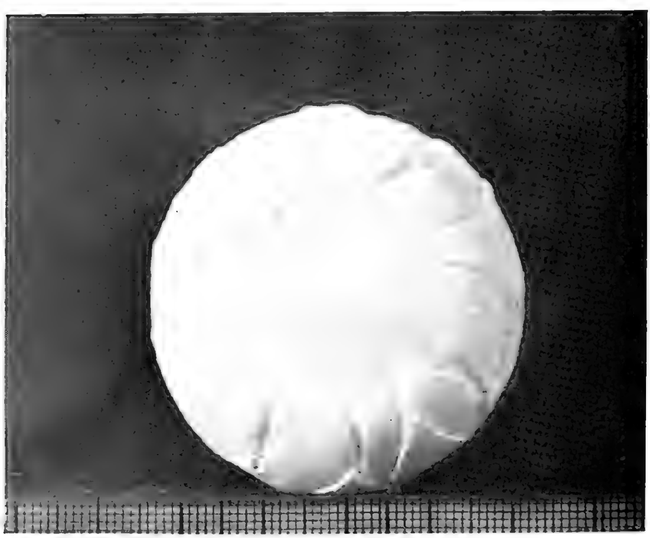
When a vertical section is cut through the axis of one of the deformed columns, the undeformed ends of the column are seen to terminate within the substance of the column in the form of rather obtuse cones pointing toward each other, and these, under the pressure, slowly advance toward one another, thin layers of the marble shearing off their faces and being forced outward, thus causing the lateral expansion of the column under deformation. As this continues, the cones at either end become gradually sheared away, and when deformation is very far advanced they eventually disappear. Each little layer of marble, however, as it is sheared off the face of the cone in the line of a tangent to it, becomes cut across by planes of movement along which other layers are being sheared off in the direction of other tangents, so that the whole medial portion of the column



(a) Cube of Carrara marble before and after deformation



(b) Prism of Carrara marble before and after deformation



(c) Sphere of Carrara marbel after deformation

is slowly forced outward, moving along a complicated series of intersecting planes of shearing, which gives the diamond or leaf-shaped pattern on the surface of the deformed column.

In some cases where the deformation of the tube has been less symmetrical the upper portion of the column is found to have sheared down over the lower portion, the movement being concentrated along a series of parallel planes forming a sort of distributed fault, the rock, however, still retaining its continuity and being free from fissures (Plate IV, Fig. *c*).

When a thin section of a column which has been deformed in alum is examined under the microscope, all the individual grains of calcite are found to exhibit polysynthetic twinning, showing that they have all been more or less deformed, but as before, the chief movement in the rock is seen to have taken place along planes of shearing which traverse the rock and whose course is indicated by little lines of granulated calcite. In order to ascertain the strength of the marble after deformation, two of the deformed columns were tested in compression. They crushed at loads of 750 lbs. and 850 lbs. respectively, while a column of the original rock has a crushing load of 4,380 lbs. The deformed marble, therefore, while firm, is much weaker than the original rock.

2. CUBES, SQUARE PRISMS, AND SPHERES

In other experiments cubes, square prisms, and spheres of the marble were deformed. In one of these a cube nearly an inch on each side was by compression in three successive copper tubes reduced to a flat cake measuring 1.36 inches by 1.38 inches and 0.55 inch thick. The maximum load employed was 219,500 lbs., or approximately 110 tons.

This deformed cube was still hard and solid and showed no traces of a pulverulent character. It is clear from its form that the movements which it has undergone are identical in general character with those which developed the artichoke structure in the case of the marble columns. On the sides of the cubes two sets of intersecting lines, along which shearing has taken place, are seen. This shearing is most pronounced at the corners of the block which tend to shear down in pieces having approximately the form of the "leaves" of the

artichoke above mentioned. On the upper surface of the flattened cake a large number of lines are seen which follow rude polygonal and more or less concentric curves around the center of the surface, which mark the borders of areas differing slightly in elevation. There are also a few vertical lines running outward toward the corners. These areas outlined on this surface are bases of rudely wedge-shaped forms which moved downward and outward. Thus the whole mass flattened out (Plate V, Fig. *a*).

A series of experiments was then made using prisms of Carrara marble. In the first of these a prism 1.575 inches high and 1.1 inches in diameter was embedded in alum in a copper tube, and the whole was squeezed down under a load of 113,000 lbs. In this experiment the tube, while retaining its original diameter at one end, spread out under the pressure at the other, and the marble column developed a graceful, rectangular, bell-shaped form, ornamented by the same beautiful pattern of triangular leaves around the end where movement had taken place. The height had been reduced to 1.2 inches (Plate V, Fig. *b*).

In the others the inclosing tube bulged at the middle in the usual manner and yielded shapes like that of the column in Plate IV, Fig. *b*, in which the zone of maximum movement was in the center of the column, which was therefore ornamented by a frill of leaflike forms in low relief. In these the load required for deformation ranged from 133,000 to 197,000 lbs., the prisms being reduced in height from 1.575 to from 1.1 to 1 inch.

A number of spheres 1.5 inches in diameter were then deformed in heavy copper tubes. By the movement the spheres were flattened to spheroids of wonderful form and beautifully ornamented, around the zone of maximum movement, by a garland of the same graceful leaflike shapes already described. The shearing which developed these spheroids is exceedingly complicated, layer after layer of the marble passing outward along the zone of maximum movement and upward toward the axes of the spheroids, each partially overlapping the one beneath, as shown in Plate V, Fig. *c*. The resulting spheroidal mass, however, is a hard, solid body of marble and shows no tendency to break in one direction rather than another. The movements, although concentrated along certain planes, do not take

place in planes of fracture, for the rock remains intact. The movement is that of a very stiff but nevertheless plastic mass.

In all the experiments just described the marble was completely surrounded by the embedding material. As the experiment proceeds, however, this flows away from about the top and bottom of the column or sphere where the pressure is greatest, and the rock is thus really caught between the upper and lower press plates of the machine, great lateral pressure however being at the same time exerted by the alum and its inclosing copper tube, and the conditions of differential pressure being thus secured.

Other experiments, however, show that a certain, though less pronounced, deformation will be produced if the marble remains in the middle of a mass of alum and is submitted only to pressure exerted by the moving alum itself, so that, if the differential pressure be of a high order, the harder limestone will be deformed by the movement of the surrounding but relatively softer matrix, provided there is not too great a difference in the relative stiffness of the two.

As a matter of interest an experiment was made to ascertain whether it would be possible to drive a nail through a mass of marble, under conditions of differential pressure such as those described above. A short nail, 0.1 inch in diameter and with a broad, flat head, was made of hardened steel. Two disks of steel were then prepared, through each of which a hole the size of the nail was drilled. A disk of marble 0.2 inch in diameter was then placed between the two steel disks and the nail was placed in the hole in the upper steel disk, so that it rested in a vertical position on the center of the marble plate. The whole was then placed in a copper tube and embedded in alum in the usual manner. Pressure was then applied and the whole was squeezed down. On dissolving away the alum the upper steel plate was found to have been distinctly bent by the moving alum, the head of the nail was broken into small pieces, but the shank of the nail had passed completely through the marble disk, making a clean, well-defined hole in the upper portion and shoving out a little conical-shaped piece of marble before it on the lower surface of the disk. The marble showed no trace of crack or fissure—the steel had passed directly through its substance. A photograph of the plate upon the completion of the experiment is shown in Plate VI, Fig. *a*, a new

nail of the same dimensions as the former one being inserted in the hole made by the latter.

B. LITHOGRAPHIC LIMESTONE: SOLENHOFEN, BAVARIA

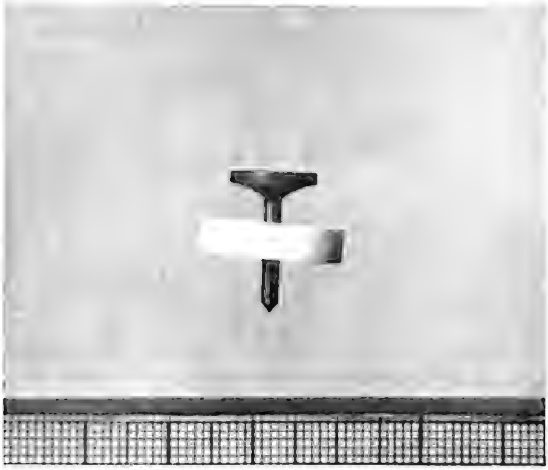
This is a buff-colored limestone of extremely fine and absolutely uniform grain, containing about $3\frac{1}{2}$ per cent of various impurities. It breaks into a splintery or conchoidal fracture. When a column of this rock is deformed in paraffine the result is similar to that obtained with Carrara marble, and in almost every case the same transverse cracks develop upon the removal of the embedding material.

In an experiment in which the rock was deformed in alum the column presented one of those highly interesting forms sometimes seen in deformed Carrara marble, dolomite, etc. This is produced by the development of a complete system of minute parallel faults crossing the column at an angle of 65° to the horizontal. The upper portion of the column thus tends to shear down along these planes, the rock however remaining hard and solid, indicating a deformation under conditions intermediate between those of the zone of fracture and the zone of flow, but more nearly approximating those of the latter.

C. FOSSILIFEROUS LIMESTONE: BELGIUM

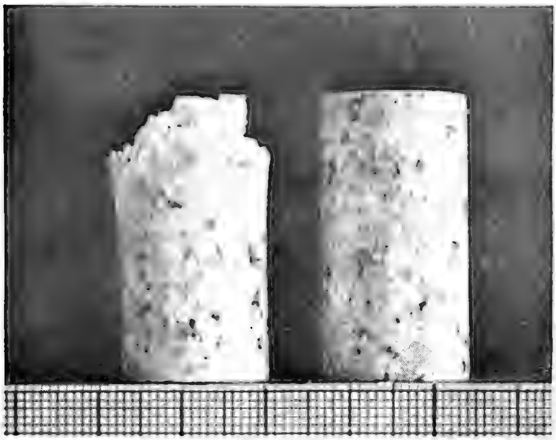
This is a dark-gray, highly fossiliferous limestone.

A column was embedded in alum and deformed in the usual manner. The height of the column was reduced from 1.574 inches to 1.4 inches, and the column yielded to pressure in such a manner that instead of bulging symmetrically it developed a movement exactly like that described in the experiment with Solenhofen limestone; that is to say, the upper portion of the column moved down over the lower portion at an angle of about 45°, the movement being concentrated along a strip about half an inch wide. In this strip there were several parallel planes in which the movement was especially pronounced, but within this zone the whole mass was seen to have been more or less plastic. Thin sections of the rock in this portion of the column when examined under the microscope showed little lines of minutely granulated material, often presenting a minutely brecciated structure, the whole constituting a species of "distributed fault." The rock after deformation was apparently as hard and solid as before.



(*a*) Steel tack forced through marble disk by differential pressure

(*b*) Dolomite—Cockeysville, Md.—before and after deformation



(*c*) Column of Baveno granite before and after compression

D. BLACK MARBLE: BELGIUM

This is the well-known ornamental stone which in commerce is known as "Belgian Black" or "Noir Fin." It is an impure, somewhat bituminous limestone, which is impalpably fine in grain, breaking with a splintery fracture like glass, and which takes a very high polish and is extensively used for interior decoration.

When thin sections are examined under the microscope the rock is found to be so fine in grain that a high power is necessary to resolve it. It is composed of minute calcite grains from 0.02 mm. to 0.002 mm. in diameter and of irregular shape, between and around which are occasional minute films and spots of a black color.

When submitted to compression in paraffine it gave rise to forms identical with those developed in the Solenhofen limestone under the same conditions.

When sulphur was employed as an embedding material, the ends of the column were found to have been forced into the central portion, with the consequent development on the exterior surface of a most complicated series of little tongues or wedge-shaped portions of the rock, sheared up one upon the other like overlapping shingles, thus giving rise to a corresponding increase in the thickness of the deformed column as its height is reduced. The rock after deformation remained hard and solid; it could be rapped sharply on a table without breaking. The cohesion may have been due in part to a little sulphur which had soaked into the column, acting as a cementing material. No trace of sulphur, however, could be detected on the surface of the column, the heat to which it was subjected after the sulphur had melted and drained away having entirely volatilized any portion of that substance that still remained adhering to the rock.

When alum was employed, the surface of the deformed column was found to be covered with a great number of sharp and more or less wedge-shaped pieces, often separated by minute open cracks, of which a great number traverse the column. The end faces of the column were also divided into separate areas, often separated by open cracks, which areas form the bases of wedges which have been faulted up or down. The resulting form is similar to that obtained when the rock is deformed in sulphur. The little wedges showed no evidence of plastic deformation. The rock was broken in a marvel-

ously complicated manner, but there no plastic flow was discernible. The rock under the conditions of the experiment acts essentially as a brittle body.

E. DOLOMITE: COCKEYSVILLE, MARYLAND

This is a typical dolomite, the analysis showing that the carbonates of lime and magnesia are present very nearly in their molecular proportions. It is white in color, practically free from impurities, perfectly crystalline, of medium grain, and is extensively employed as a building stone.

A column when deformed in paraffine wax in the usual manner was found upon the completion of the experiment to have assumed the same form as in the case of Carrara marble. The upper portion, where the deformation was greatest, showed very plainly two sets of lines crossing its surface and intersecting at angles of about 60°. The upper end of the column at a number of places was commencing to shear down in triangular-shaped masses. From the portion of the column where the deformation had been greatest a series of thin sections was prepared. When these were examined under the microscope the rock was seen to be traversed by many little branching lines of finely granulated material, which lines however intersected, giving a rude, diamond-shaped network. The individuals composing those portions of the rock between these lines were somewhat flattened in shape and showed distinct strain shadows.

The dolomite was then deformed in alum in the usual way, the load required being 33,000 lbs. The deformed column presented a striking appearance and showed in a most beautiful manner on its surface the leaflike forms due to movements along Luder's lines, described in the case of the Carrara marble, but the dolomite is seen to be somewhat less plastic than the Carrara marble, for in several places the column was torn by the movement in directions other than those followed by Luder's lines, this tearing giving rise to open and ragged rents in the substance of the column after the alum had been dissolved away. The form is very suggestive (Plate VI, Fig. *b*). The rock moved as an exceedingly stiff, semi-plastic mass. The upper portion of the column is commencing to shear off along a plane inclined at an angle of about 60° to the horizontal. The movement

however is, as has been mentioned, that of a stiff paste, not that of a brittle solid.

F. IMPURE MAGNESIAN LIMESTONE: HULL, CANADA

This is a very impure magnesian limestone, containing about 50 per cent of insoluble residue in the shape of minute subangular grains of clear quartz. The rock is of somewhat open grain and porous character and has been used very extensively for the production of hydraulic cement.

When deformed in paraffine, triangular portions of the column were found to have sheared off around the end, as in the case of other purer varieties already described. These remain adhered to the column, which also shows a marked tendency to develop cracks, crossing it at right angles to its length, i.e., at right angles to the direction of the pressure.

A column of the usual dimensions was then deformed in alum in the usual manner under a load of 31,000 lbs. On dissolving away the alum, however, the deformed column went to pieces, but from the shape of the fragments it could be seen that the movements developed in it had been of the nature of a complicated shearing similar to those already described.

G. BIOTITE GRANITE: BAVENO, ITALY

Columns of granite of the usual size and with a polished surface were embedded in alum inclosed in a copper tube in the usual manner and submitted to the pressure required to squeeze the whole down until the copper tube displayed signs of incipient rupture. The load required for this purpose was 50,000 lbs.

When the alum was removed by solution, the granite at one end of the column was found to have remained intact. Toward the middle, however, the column had undergone a distinct bulging due in part at least to a movement along little planes of thrust or shearing, although the work was still quite coherent, the movement in question having given rise to a rude gneissic or schistose structure owing to the arrangement of strings of mica and grains of orthoclase parallel to the base of the column. The other end of the column where the motion had been greatest was disintegrated by the movement and fell

to powder when the alum was dissolved away. A photograph of one of the columns as it appeared when freed from the alum is shown in Plate VI, Fig. *c*, but as in this particular case the movement was not so great as in others, the gneissic structure referred to is not well seen. When examined under the microscope, both quartz and orthoclase show well-marked strain shadows, but even a very careful examination under a high power between crossed Nicols fails to show with certainty whether the shadows in question are due to an actual bending of the mineral or to a fracture of the mineral with a slight shifting along an infinite number of ultra-miscroscopic cracks.

In several cases, however, where the conditions for observation were very favorable, no signs of such cracks could be detected and the mineral seemed to have undergone an actual twisting.

The biotite individuals had been very distinctly bent and twisted.

The rock displays a remarkably perfect cataclastic structure along certain lines or streaks where the quartz and orthoclase are represented by larger fragments, which, however, are mingled with those of smaller size, as well as with others which pass into almost ultramicroscopic dimensions.

SUMMARY

1. Under the differential pressures developed by this method of experimentation, that is by employing Kick's process, using fused alum or the other embedding materials employed, and tubes of copper with walls of from 0.125 to 0.25 inch (3.175 to 6.38 mm.) in thickness, minerals which have a hardness of 5 or under (Mohs's scale), show distinct plastic deformation, this deformation being less pronounced in the case of the harder minerals.

2. The minerals above 5 on the Scale of Hardness, while not presenting any marked change in shape, in some cases show evidences of internal movement. Thus a perfect basal twinning is developed in diopside, similar to that so often seen in specimens of this mineral from the crystalline limestones of the Grenville series.

3. In the case of very hard minerals, no evidence of plastic flow was discernible; their structure was broken down and they were reduced to powder.

4. Under the differential pressure fluorspar not only changed its form but also its color.

5. The softer rocks, such as Carrara marble, are readily deformed, the shapes assumed varying somewhat with the character of the material in which the rock is embedded during deformation. The movement takes place in part by distortion of the calcite grains and in part by the development of a cataclastic structure in the rock.

6. Crystalline dolomite is more resistant. The movement induced in it resembles that produced in a very stiff paste. This movement takes place chiefly through the development of cataclastic structure.

7. Very fine-grained massive limestones display a movement in which flowing and fracture are combined.

8. The harder rocks, like granite, crumble under the pressure, although in those places where the movement is very slight, the rocks develop an indistinct foliated structure owing to the granulation (cataclastic structure), with movements in the granulated portion of the rock.

9. For the development of a flow structure in the harder rocks, much higher differential pressures are required than are obtained by this process—such differential pressures, for instance, as may be secured when the rocks are inclosed in steel before being submitted to the deforming load.

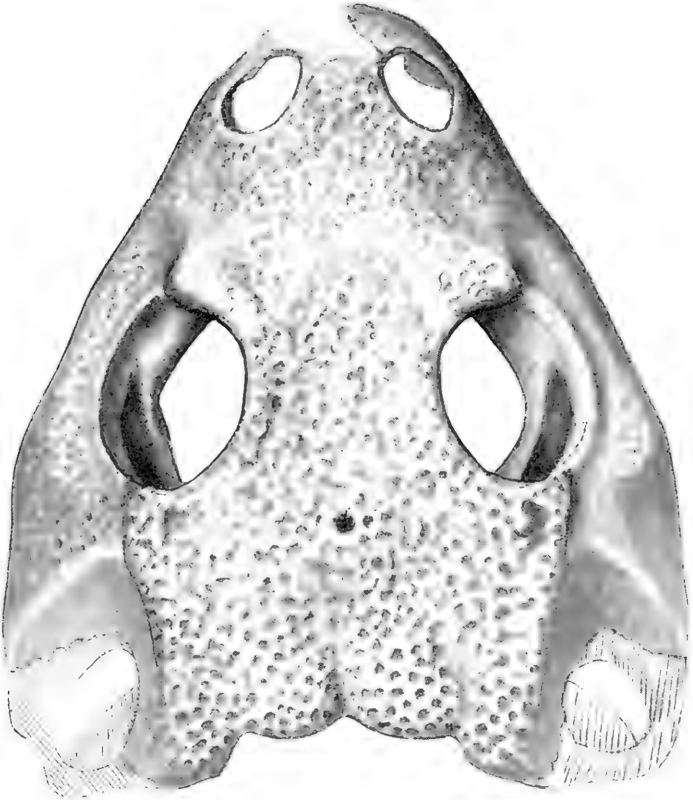
DISSOROPHUS COPE

S. W. WILLISTON
The University of Chicago

The material herein described and figured was collected by the writer from the upper or Clear Fork Division of the Texas Red-beds on Coffee Creek, in August, 1909. It comprises a nearly complete skull, but little distorted, the two scapulae with attached cleithra, neither complete, but the two supplementing each other nearly perfectly; the two complete clavicles attached to the incomplete interclavicle; the two humeri, one complete save for the capitellar angle, the other with the distal part quite complete and the proximal portion missing; two attached proximal carpals, several vertebrae and fragments of ribs, the nearly complete carapace, a broken and somewhat distorted pelvis, a femur, and fragments of epipodial bones.

For the most part, the surface of the skull is unimpaired, showing deep, almost circular pits, with narrow, reticulating ridges between them. The pittings seem to be most pronounced in the upper posterior part. There are no indications of mucous grooves, and I am convinced that, were they originally present, evidences of them would be apparent. Nor, as in the case of the skulls of *Cacops*, can I distinguish the sutures.

The skull is very broad posteriorly, with a rounded, obtuse muzzle. The orbits are situated about midway in its length; they are rather small, nearly circular in outline, and broadly separated. The table of the cranium, back of the orbits, is rather broader than long, a little wider anteriorly, with a broad emargination behind; it is nearly plane, with its margins elevated. The parietal foramen is situated a little back of a line drawn through the posterior margin of the orbits. Just back of each orbit there is a distinct depression, as in *Cacops*, apparently for the lodgment of some gland. In the middle part behind there is, on each side, a prominent, nearly hemispherical elevation, deeply impressed with large pits; they correspond to the prominent rugosities of the *Cacops* skull, but are much more rounded and less



angular. Behind, these swellings are partly separated by an angular emargination of the hind border. The epiotic region on each side is produced backward considerably beyond the transverse line of the rounded swellings. The broad surface between the orbits is shallowly concave transversely. The thickened upper margin of the orbits is nearly horizontal to the middle of the orbit in front, where there is a rugosity, the outer border of which is nearly vertical. The face in front of the orbits is convex, with a depression on each side in front of the orbital rugosity. The nares are large, oval in outline, and are directed upward and outward and forward. Below and a little behind the orbits there is a distinct elevation or rugosity. The posterior lateral or temporal region is unfortunately wanting on each side, or rather the parts were so mutilated that they could not be joined. The structure here is quite surely as in *Cacops*, the epiotic prolongation with its attached quadrate inclosing the ear opening at the bottom of a cavity. The upper margin of this opening is preserved in part on the left side, as is also most of the smooth bone forming the anterior part of the auditory cavity, the ridge limiting this surface from the roughened exterior of the side of the skull in front of it running downward and backward from a point about ten millimeters back of the orbital margin, to the jugal border.

On the palatal side of the skull the basioccipital, basisphenoid, and parasphenoid could not be recovered, nor the vomerine portion in front. On the left side the pterygoid and palatine regions are nearly perfect and undistorted, save for the interior border of the nares. The nareal opening is long and narrow, the anterior margin a little in advance of the posterior border of the external opening. In front the external border is very close to the dental margin; behind, it is removed a few millimeters. Near the posterior margin of the opening there is a single large tooth, as in *Cacops*, and doubtless there was another on the vomers at the anterior inner border; no other palatine or pterygoid teeth are visible. The infratemporal opening between the pterygoid and jugal margin is shorter and narrower than in *Cacops*, and the lateral process, doubtless corresponding to the transpalatine, is smaller. The basisphenoid process of the pterygoid is stout, transverse, and nearly horizontal. Evidently the structure throughout of the palatal surface was quite alike in the

two genera. Parts only of the walls of the rhinencephalic chamber are preserved.

The maxillary teeth, which extend backward to opposite the beginning of the infratemporal opening, are all very small, and are much more numerous than in *Cacops;* I count about forty-five in each maxilla. Those preserved entire are scarcely more than two millimeters in length.

The mandibles, which, with the exception of the extreme anterior end, are preserved complete, are, like those of *Cacops*, slender bones, deepest immediately in front of the cotylus, with a relatively high coronoid process, which fitted into the infratemporal fossa. I count about thirty-five teeth in each dentary, as preserved. The external surface, at least posteriorly, is closely impressed with circular or oval pits, like those of the cranial table.

Carapace.—The carapace, as preserved, is of essentially the same character as that of *Cacops*, but of a far greater development. In the series, as adjusted, there are indications of twelve or thirteen vertebrae participating in the shield, and others possibly are lost. The whole number may have been the same as in *Cacops aspidephorus*, that is, fifteen, but I suspect there were more. The first dermal shield, covering three or four vertebrae, appears not to have been intimately associated with the spines of the vertebrae. It is very large, not much broader than long, and heavy. Its front border is very obtusely angular in the middle with the borders receding and rounded. The lateral borders are subparallel and gently convex in outline. The posterior border has a gentle emargination in the middle with the lateral sides slightly convex behind. The planes of the sides have an angle of nearly forty-five degrees with each other and are broadly rounded in their union. The dorsal surface is rather deeply pitted, the depressions rounded or oval with reticulating ridges between them. The under surface is smooth, and appears not to have been underlaid with lateral expansions of the spines. Back of this shield, on the under side, there are nine spine dilatations, the first six or seven complete in the specimen. They are thin, flat plates, apparently co-ossified with the rather slender spines above, directed nearly transversely, with a less angle of declivity than has the nuchal or scapular shield. The outer extremities are narrowed or obtusely pointed, their upper

surface beveled both in front and behind for the dorsal shields. Their surface is smooth throughout.

The dorsal shields are rather stout, elongate bones, rounded on their outer extremities, pitted on their dorsal surface like the nuchal shield, forming a rather uniform arc of a circle, with less steepness on the sides than that of the nuchal shield. These shields, thick in their middle line, thinned along their anterior and posterior margins, leave a space of from two to four millimeters between their adjacent borders, in which the smooth surface of the spinal expansions is visible.

Vertebrae.—Not many of the vertebrae are preserved, and such as are, are not in the best condition. They do not seem to differ from the vertebrae of *Cacops* in any essential respect. The vertebra connected with the first dorsal spinous expansion has the proximal end of the ribs attached. It is broad and flat, articulating with the transverse process and hypocentrum like the early ribs of *Cacops.* The ribs evidently had no uncinate projections like those of *Aspidosaurus* or *Euchirosaurus.* The under surface of the more posterior expansions is shown characteristically in Broili's figure (*Paleontographica,* LI, Pl. V, Fig. 5*b*).

Scapula.—The scapula of *Dissorophus* differs markedly from that of *Cacops* in its greater robustness and in its more upright position. The posterior border is thickened and has a more pronounced convexity near its middle. The preglenoid facet is very prominent as a sharp ridge, immediately below which is the opening of the infraglenoid or supracoracoid canal and, close by, back of the lower part of the same facet, is the opening of the glenoid canal. The ridge continuous with the preglenoid facet is less prominent than in *Cacops;* the post-glenoid part, or metacoracoid, is more extensive, the concavity between it and the hind border of the shaft is deeper. On the inner side the deep fossa into which opens the supraglenoid and infraglenoid canals is deeper and shorter, and the epicoracoid portion is much broader below and internally to this fossa. The opening for the glenoid canal on the inner side, as in *Cacops* and *Trematops,* is opposite the lower part of the fossa.

The three glenoid foramina or canals, which I have called the supraglenoid, glenoid, and infraglenoid, appear to be characteristic of the rhachitomous amphibians, if not of the temnospondyles. I have

no knowledge of the occurrence of all three in other vertebrates. In *Labidosaurus* the scapula-coracoid, which has a wonderful resemblance to these forms, has a distinct supraglenoid opening in the same position, opening internally in the same way with the inner opening of the infraglenoid foramen in a smaller fossa. So, also, in the pelycosaurs there is a corresponding foramen, though it may pierce the bone more in advance of the glenoid depression. In none of these forms, however, have I been able to distinguish a glenoid foramen; certainly there is no inner opening corresponding to that of the amphibians in any of these reptiles. In *Varanosaurus* the sutural line between the scapula and coracoid (epicoracoid or procoracoid) passes backward through the preglenoid facet, and through the place where the glenoid foramen should be, were there one. The suture for the metacoracoid (coracoid auct.) is back of this place in *Varanosaurus*. Unfortunately, in none of the amphibians have I, or others, been able to distinguish the divisional sutures between scapula and coracoid in front, or that between the scapula and coracoid and the metacoracoid behind. There can be scarcely a doubt that the extraordinary resemblance of the amphibian girdle to that of the cotylosaurs and pelycosaurs extends also to its intimate structure, and that the relations between the scapula, coracoid, and metacoracoid are identical in the two groups. The demonstration of this, however, is not yet possible. What the significance of the glenoid and supraglenoid canals is in the amphibians, the supraglenoid in the reptiles, must await further researches. The latter is present in *Iquara*.

The cleithrum or supraclavicle is a much heavier, but more slender bone in *Dissorophus* than in *Cacops*. It lies, as in that genus, loosely over the top of the scapula, not suturally united with it, arching rooflike over the top. In front it descends over the rounded superior anterior angle of the scapula, fitting into a depression of that bone. Below, it unites by a long oblique suture with the upper end of the clavicle, extending as a narrow, anteriorly curved process quite to the place where the coracoid turns inward, that is doubtless to the sutural line between scapula and coracoid.

Various views have been entertained as to the origin, nature, and fate of this bone; the one usually accepted is that of Gegenbaur, that it represents a like bone in *Polypterus;* and this seems to be altogether

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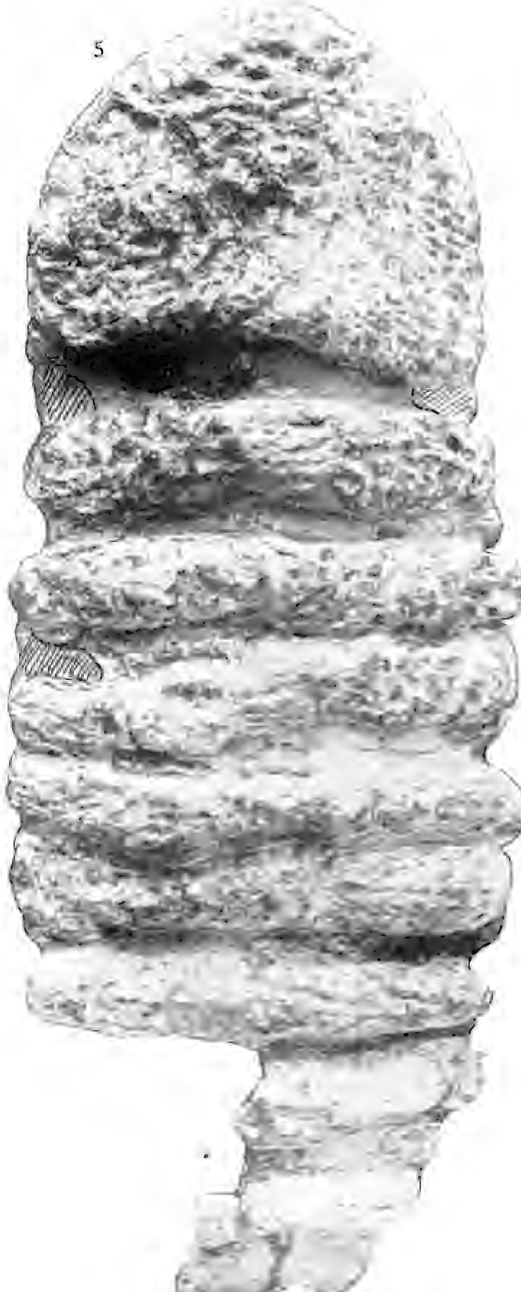

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probable. As to its fate, the only theory suggested is that of Gaudry, that it represents the acromial ossification of the higher vertebrates; and this too seems not unreasonable. The union between clavicle and cleithrum in *Dissorophus* is a very close, sutural one; in the early reptiles only the lower end of the cleithrum is left; the co-ossification of this with the scapula would account for the acromion, if it be not a mere epiphysial ossification. In *Eryops* the cleithrum is suturally united throughout with the scapula above, in the position of the suprascapula.

Interclavicle.—The interclavicle is a broad, gently concave, and thin bone, resembling that of *Cacops,* but larger and broader. It has a rounded, thin border anteriorly, and similarly rounded, thin lateral margins. Posteriorly the bone is broken away but the thickened median part indicates a posterior median extension, probably as in *Cacops.*

Clavicles.—The clavicles are large, broad, smooth bones, meeting each other in the middle line, and covering, for the most part, the interclavicle. They are convex below, with their greatest expansion some distance away from the middle. In the position in which the girdle now is, evidently the normal one, the cleithral ends are directed vertically upward, nearly parallel to each other, with an interval of a little more than two and a half inches between their upper extremities, which are suturally and closely united to the lower ends of the cleithra or supraclavicles. The upper extremity is much stouter and broader than is the case with *Cacops.*

Upon the whole, the pectoral girdle, both primary and secondary, is remarkable for its stoutness and firm articulations.

Humerus.—Of the two humeri, the left is preserved completely save the capitellar angle, while the right has the lower end perfect with the upper extremity wanting. In the figures the capitellar portion has been reversed from the right side. In general shape and structure the bone resembles that of *Cacops* closely, so closely that there may be difficulty in distinguishing them in ill-preserved specimens. The humerus of *Dissorophus* is distinctly stouter, with the ends a little more expanded and the lateral curvatures a little deeper; the entepicondylar expansion is stouter.

Femur.—The right femur is preserved in pretty good condition

save the external condyle and a part of the lower portion of the crest. Its resemblance to the femur of *Cacops* is close, but, like the humerus, differs in its greater stoutness. The adductor crest is heavier, and not as deep, the shaft is distinctly stouter. The articular surface for the tibia is rather better defined than in any of the specimens of *Cacops* examined. The surface is flattened, or with a gentle antero-posterior convexity with sharp rims. It is broadest on the inner side, narrower in the middle, and again somewhat expanded from before back on the outer side. The surface looks backward at an angle of about forty-five degrees from the longitudinal plane of the bone, with a light obliquity inward.

A large part of the left innominate bone is preserved, enough to demonstrate its close resemblance to the corresponding element of *Cacops*. Nor do the proximal ends of the tibia and ulna differ materially; like all the other parts, they are stouter.

The relationships between *Dissorophus* and *Cacops* are very evident, so evident, indeed, that for some time I was in doubt of their generic distinction. It would seem, however, that the much greater development of the carapace in *Dissorophus* together with the presence of the very large shield, which seems to be entirely absent in *Cacops*, together with other differences in skull and pectoral girdle, is amply sufficient to separate the two forms generically. And it is also evident that these two genera, presenting the unique characters they do, are entitled to a higher rank than genera. The characters of the family Dissorophidae I have already given, as based upon *Cacops* and *Dissorophus*. Whether or not the genus *Aspidosaurus* Broili should be placed in the same family is a matter of doubt. So far as the carapace is concerned the differences seem radical, in the absence of spinous expansions of *Aspidosaurus*, the dermal shields forming a shingle-like imbrication. However, other characters, so far as the known details furnished by the type specimen of *Aspidosaurus* are concerned, seem very like those of this family, and it is possible that the family characters may have to be emended in the future to include Broili's genus.

Although the known remains of *Zatrachys* are yet very meager, it would seem certain that the genus cannot be included with *Dissorophus*, and that the family Zatrachydidae will find eventual justi-

fication. The remarkable characters of *Trematops* also justify the creation of a family for its reception, with possibly *Acheloma* as an allied genus. Of the other American genera of temnospondyles, *Eryops* has long been considered of family rank, as also *Trimerorhachis*. None of these genera, so far as my knowledge goes, possessed either dermal or ventral armature, other than the carapacial development of the Dissorophidae and Zatrachydidae. Dermal plates have been accredited to *Trimerorhachis*, but I believe wrongly, since several specimens in the Chicago collection although including almost all parts of the skeleton give not the slightest indication of such. Nor were there any dermal plates, ventral or dorsal, in either *Trematops* or *Eryops*, and I am convinced that none will be found in *Zatrachys*, when better known. That there were amphibians in the American Permian with isolated dermal scutes is, I believe, certain from the evidence furnished by the Orlando bone bed, though perhaps they were all small animals. Thevenin has discovered dermal ossifications in *Euchirosaurus*, which he believes to be identical with *Actinodon*, and, furthermore, from his figure and descriptions of the ribs in that genus, it is quite certain that its relationship with *Eryops* is not nearly so close as has been thought, and as Thevenin believes. Similarly expanded ribs are characteristic of *Aspidosaurus*, apparently. Furthermore, we have no evidence so far, among the American forms, of a long tail, unless it be in *Trimerorhachis*, which differs so much in many ways from the other temnospondyles that it may well be it had also a long tail. Thevenin gives the number of presacral vertebrae in *Euchirosaurus* as twenty-two or twenty-three, I have determined the same numbers in *Trematops*, while in *Cacops* the number is positively fixed at twenty-one. Branson[1] gives the number for *Eryops* as twenty-five or twenty-six, though he found in no specimen more than twenty-four in a continuous series. Perhaps there is some variation in the various genera, but evidently the number never greatly exceeded twenty-two. Branson speaks of a small isolated arch in the atlas; if he be correct, the atlas differs materially from those of *Trematops*, *Cacops*, and *Dissorophus*. But I believe it will be found that the *Eryops* atlas was of like structure, that is, with co-ossified neuro- and hypocentra, with the sides of two neurocentra separated above. Bran-

[1] *Journal of Geology*, VIII, 603.

son described all the presacral vertebrae of *Eryops* as having double-headed ribs, attached to diapophysis and hypocentrum, while in *Cacops* it is only the anterior vertebrae which articulate with the hypocentrum and this is also clearly the condition in *Dissorophus*.

So far these are all the described genera of rhachitomous amphibia from the American Permian. The genus *Cricotillus* Case I suspect is identical with *Crossotelos* Case, a "Microsaurian" amphibian, while *Cricotus* is an embolomerous form.

Recently Case has discovered that *Otocoelus* is identical with *Dissorophus*, as indeed the figures given by Cope indicated. Whether or not the genus *Conodectes* Cope is also a related temnospondyl it is impossible to determine without examination of the type. The description given by the author of the genus is utterly inadequate for its recognition.

Following is a taxonomic summary of the known American Permian Amphibia.

CAUDATA.
- Lysorophidae Williston, 1909 (Paterosauridae Broili, 1904).
  - Lysorophus Cope, 1877.
    - tricarinatus Cope, 1877, Illinois, Texas, Oklahoma.

"MICROSAURIA" (Diplocaulia Moodie).
- Diplocaulidae Cope, 1881.
  - Diplocaulus Cope, 1877.
    - salamandroides Cope, 1877, Illinois.
    - magnicornis Cope, 1882, Texas.
    - limbatus Cope, 1896, Texas.
    - Copei Broili, 1904, Texas.
    - pusillus Broili, 1904, Texas.
- Crossotelidae Williston, 1909.
  - Crossotelos Case, 1903, Oklahoma.
    - annulatus Case, 1903.
  - ? Cricotillus Case, 1903, Oklahoma.
    - brachydens Case, 1903.

TEMNOSPONDYLI.
- Embolomeri.
  - Cricotidae Cope, 1884.
    - Cricotus Cope, 1873.
      - heteroclitus Cope, 1875, Illinois, Kansas.
      - gibsoni Cope, 1877, Illinois.
      - crassidiscus Cope, 1884, Texas.
      - hypantricus Cope, 1884, Texas.

Rhachitomi.
- Eryopidae Cope, 1882.
  - Eryops Cope, 1877.
    - megacephalus Cope, 1877, Texas.
    - erythroliticus Cope, 1878, Texas.
    - ferricolus Cope, 1878, Texas.
    - reticulatus Cope, 1881, New Mexico.
    - latus Case, 1903, Texas.
  - Anisodexis Cope, 1882.
    - imbricarius Cope, 1882, Texas.
- Zatrachydidae, Nov.
  - Zatrachys Cope, 1878.
    - serratus Cope, 1878, Texas.
    - apicalis Cope, 1881, New Mexico.
    - conchigerus Cope, 1896, Texas.
    - microphthalmus Cope, 1896, Texas.
- Trematopsidae Williston, 1910.
  - Trematops Williston, 1909.
    - milleri Williston, 1909, Texas.
  - ? Acheloma Cope, 1882.
    - cumminsi Cope, 1882, Texas.
- Dissorophidae Williston, 1910. (Otocoelidae Cope.)
  - Dissorophus Cope, 1895.
    - multicinctus Cope (? articulatus Cope), Texas.
  - Cacops Williston, 1910.
    - aspidephorus Williston, 1910, Texas.
  - ? Aspidosaurus Broili, 1904.
    - chiton Broili, 1904, Texas.
- Trimerorhachidae Cope, 1891.
  - Trimerorhachis Cope, 1878.
    - insignis Cope, 1878, Texas.
    - bilobatus Cope, 1883, Texas.
    - conangulus Cope, 1896, Texas.
    - mesops Cope, 1896, Texas.
    - leptorhynchus Case, 1903, Oklahoma.
- Incertae sedis.
  - Cardiacephalus Broili, 1904.
    - sternbergi Broili, 1904, Texas.

EXPLANATION OF PLATES

PLATE I.—*Dissorophus multicinctus* Cope; dorsal view of skull. Three-fourths natural size.

PLATE II.—*Dissorophus multicinctus* Cope. 1, left humerus from in front; 2, the same from inner side; 3, 4, proximal carpal bones; 5, dorsal view of carapace. All figures natural size.

PLATE III.—*Dissorophus multicinctus* Cope. 1, right scapula-coracoid, with attached cleithrum, from outer side; 2, right femur, from behind; 3, clavicular arch, from below. All f gures natural size.

A MOUNTED SKELETON OF PLATECARPUS

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In the summer of 1903, Professor E. B. Branson, then a student of the University of Chicago, discovered, near the mouth of Hell Creek in Logan County, Kansas, and collected with my aid, a remarkably complete specimen of a species of *Platecarpus*, which I refer, with little hesitation, to *P.* (*Holosaurus*) *abruptus* Marsh. In its vicinity another specimen almost identical with it in size and characters was discovered by Mr. E. Ball of the same party. A brief reference to some of the characters of the more complete of these two specimens was given by me in this *Journal* for January, 1904 (p. 30), and, later, Mr. S. R. Capps, under my advice, made a careful study of the hind extremity, publishing his results in this *Journal* for May, 1907 (p. 350). Since then both of these specimens have been thoroughly worked out of the matrix by Mr. Paul Miller, and one of them has been mounted as a wall specimen in the Walker Museum of the University of Chicago, a photograph of which is given in the present communication. It was first planned to mount the more perfect of the two specimens, but the horizontal flattening of the skull rendered it less adaptable for a plaque mount, and the specimen has been reserved for a free skeletal mount at some later time. The less complete of the two has therefore been placed upon the wall, its missing parts reproduced by casts from the more perfect one; this specimen fortunately had its skull bones preserved separately, in a macerated condition, with but little or no distortion, permitting their articulation in a normal position. The vertebral column was very complete and continuous to about the seventieth vertebra, that is the forty-seventh of the tail. The pectoral girdle, save the right humerus, and most of the hind paddles and pelvic girdle were preserved, in large part, in their natural relations; of the ribs many of the shorter ones were gone; these, together with the distal portion of the tail, have been reproduced from the other specimen, and the left humerus has been used instead

of the right. The specimen, therefore, has very little that is conjectural about it save the terminal phalanges of the paddles. Of the more complete specimen the vertebral column lay with every vertebra articulated and in position from the skull almost to the extreme tip of the tail, the last one preserved measuring about eight millimeters in diameter. Of the many hundreds of specimens of mosasaurs which I have collected, I have seen but very few with the extreme tip of the tail preserved in position; the small nodular terminal centra, feebly attached in life, are almost always dispersed. Of this series of vertebrae seven are cervical, twenty-three are dorsal, the first non-costiferous vertebra being the twenty-fourth. This is one more than I have found positively in other specimens, and in the specimen mounted, and is precisely the number I found in specimens of *Tylosaurus proriger;* while Osborn has recorded twenty-two as the number found by him in a specimen of *Tylosaurus dyspelor.* Of the caudals, six are pygals, one more than I have found in specimens of *Platecarpus coryphaeus.* Seventy caudal vertebrae were preserved in position, to which perhaps six or eight terminal nodular ones may be added, making eighty-five or eighty-six in all, about the number estimated by me as characteristic of *Platecarpus.* The distal caudals have, it is seen, a distinct elevation of the spines, a character I have never seen in other specimens of *Platecarpus.* Osborn has figured the tail of *Tylosaurus dyspelor,*[1] with a distinct elevation of the distal spines. His figures and statements do not need corroboration; the character certainly exists in the figured specimen. On the other hand, v. Huene[2] has recently figured specimens which he refers to the same species, which do not

[1] *Memoirs American Museum,* I, Pt. IV, 178.

[2] *Geologische paleont. Abhandlungen* (1910), VIII, 297.

show this distal expansion of the tail, and which the author denies. He also finds in the tail positive evidence of ninety-six caudal vertebrae (including the pygals), and estimates, though I think on insufficient foundation, twelve or fourteen more. (I may say, parenthetically, that the position in which bones are found in the Kansas chalk has no value as an indication of missing parts.) In the species *T. proriger* I have found eighty-eight as the full number in a specimen, in which every vertebra was found articulated, from the skull, to the minute ones of the tail. This specimen I have recently re-examined in the University of Kansas. There may have been one or two vestigial nodules at the extreme tip missing. In this specimen there was no conjecture, each vertebra as it was taken from its articulated position was numbered, and placed in its original position in the mounted specimen. From all of which facts it would seem to be evident that there may be individual or specific differences as regards the number of vertebrae in the mosasaurs.

In comparison of the paddles as shown in this restoration and as figured by Capps (*op. cit.*) it will be seen that the numbers of phalanges do not quite agree. A further examination of the various paddles of this genus leads me to the conclusion that the supposed missing phalanges in the specimen figured by Capps were not real, and that practically all the phalanges were secured. I think that the numbers for the different toes were essentially those originally given by Marsh for *Platecarpus* (*Lestosaurus*).

Here too, as is conclusively shown by a comparison of the paddles of the American Museum specimen of *Tylosaurus dyspelor* with that of *Tylosaurus proriger* of the University of Kansas, there are either individual or specific differences.

Huene finds in one of his specimens of *T. dyspelor* what he believes to be vestigial nasal bones. I quite agree with him that the nasal bones in the mosasaurs are not fused with the extremity of the premaxillae, but I have never found in any of the numerous specimens of mosasaurs any vestigial bones that seem beyond doubt to be the real nasals, such as Huene figures. I have seen in several skulls remains of the suture between the post-orbitals and post-frontals, but almost invariably the suture is wholly obliterated, and it may be possible that the nasal bones are thus indistinguishably fused in most specimens of

Platecarpus. Quite certain it is that in the specimens under consideration there are no such separate bones. Incidentally I may mention that in *Pteranodon* among pterodactyls the fibula is supposed to be absolutely wanting, yet in a specimen in our collection I find distinct remains of it fused with the tibia.

I have for some time agreed with Thyng and v. Huene in their conclusion that the real squamosal bone of the mosasaurs (and lizards) is that connecting the post-orbital with the so-called supratemporal bone, though Thyng, not reading my text but examining my figure alone, goes to considerable trouble to prove that I was wrong (see *Biological Bulletin*, VII, 189 ff.). But I agree with neither of these authors in considering the posterior element, that intercalated between the squamosal and exoccipital and pro-otic, as the so-called supratemporal. It is a matter of surprise to me how persistently all students of the temporal arch of the mosasaurs and lizards have ignored the description and figures of this bone given by Cope and myself. From Baur to the present time, save Merriam and myself, no one has paid any heed to Cope's descriptions. At the risk of being discursive I will quote what I have previously published in the article already quoted:

> Baur vigorously urged that the bone at the end of the suspensorium is the squamosal, but Baur never fully understood the relations of this bone in the mosasaurs, as is evidenced by his faulty description of it.[1] As Cope has repeatedly affirmed and as I have confirmed,[2] this so-called squamosal (supratemporal Huene) of the mosasaurs is intercalated between the exoccipital and the pro-otic, extending far inward, nearly to the surface of the braincase. It needs but a moment's consideration by any one familiar with the relations of this bone in these animals and in the mammals to be convinced that such remarkably different conditions cannot be those of the same bone. The inner part of the (squamosal) [deeply wedged in as it is between two cartilage bones] corresponds quite well with the outer part of the opisthotic, which was not found in the lizard embryo by Parker. "In some of the genera of Stegocephala the paroccipital is free from the exoccipital; in others (*Mastodonsaurus*) it is co-ossified with the exoccipital. The paroccipital is in relation to a dermal plate which is very improperly called the epiotic. I propose the name paroccipital plate for it."[3]

[1] *Journal of Morphology* (1892), VII, 14.

[2] Cope, *Trans. Amer. Phil. Soc.* (1892), XVII, 19; Williston, *Univ. Geol. Survey* (1898), IV, 121.

[3] Baur, *Journal of Morphology* (1889), III, 469.

It may be objected that the presence of an epiotic bone in the lizards is a far too primitive character, but we are now quite certain that the lizards are an extremely old group, probably dating from the Permian, and that they have not a few primitive characters, etc.

In a recent paper[1] I have again expressed the opinion that the squamosal of Baur, the supratemporal of Thyng, v. Huene, and others, is in reality the "epiotic," paroccipital plate, intercalare, tabulare, or post-temporal (for these are some of the names the bone has received) of the stegocephs.

In his discussion of the elements of the mandible I do not think that v. Huene does Baur justice. Baur it was who, for the first time, correctly made out the structure of the reptilian mandible. His mistake was in starting with the turtles as the basis of his revised nomenclature, instead of the crocodile, to which the names of the bones were originally given. This fact I tried to make clear in *Science*, and in my paper on the plesiosaurs,[2] where I introduced, for Baur's angular, the name prearticular, now generally used. Kingsley, later, overlooking this term (very naturally, for it was hidden away), reached the same conclusion, but gave the name dermarticular for the element in question, a term in some respects more appropriate than mine, but, because of doubtful homologies, not to be unreservedly recommended. The prearticular occurs as an independent bone in many, if not all dinosaurs, the chelonia, plesiosaurs, pelycosaurs, and probably all the old reptiles and stegocephs.

[1] *American Journal of Anatomy*, X, 82.

[2] *Field Columbian Museum Publications*, No. 73, p. 30.

OLDER DRIFTS IN THE ST. CROIX REGION[1]

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Some of the glacial features of the St. Croix–Dalles quadrangle were described in a previous number of this *Journal*.[2] That paper was based upon field studies during the summer of 1904. Up to that time no certain evidence of any drift-sheet older than the Wisconsin stage of glaciation had been recognized, and in consequence that paper confined itself to a discussion of the two drifts of Wisconisn age which occur as surface formations within the quadrangle. But with the aid of a class of students from the University of Chicago, during the field season of 1905, the presence of a considerable amount of drift distinctly older than the Wisconsin red drift was clearly recognized at a number of points along the St. Croix River. Two years later a study of the deep ravines which dissect the river bluffs opposite Osceola, Wis., resulted in finding that there are two very distinct drift-sheets in this region belonging to earlier glacial epochs. The earlier of these is a sheet of grayish-black drift brought in from the northwest by a Keewatin glacier. At some later date a sheet of pinkish-red or reddish-brown drift was spread over the region by a glacier from the Labrador center coming by way of Lake Superior.

THE GRAYISH-BLACK DRIFT

The deep ravines opposite Osceola which head back from the river to the Minnesota uplands afford the best opportunities to study the buried Pleistocene deposits of the region. At the bottom of the big ravine in the south part of Section 16, Franconia (about 100 yards east of the wagon road), is a gully-bank exposing ten feet of very dark grayish to bluish-black till. This dark drift is highly calcareous and contains relatively few pebbles and these mostly small. It is largely a rock flour derived by glacial grinding from limestone and

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] R. T. Chamberlin, "The Glacial Features of the St. Croix–Dalles Region," *Jour. of Geol.*, XIII (1905), 238–56.

shale formations. The most common pebbles found in it are limestones, granites, and greenstones. In its upper portion it gradually becomes brown, passing into yellow-buff above. These brown and buff portions are obviously merely the partially oxidized phases of the drift which was originally nearly black in color. Upward the till becomes less and less calcareous, due to leaching. The great amount of calcareous and argillaceous material as well as the distinctive assemblage of crystalline pebbles in this drift indicates that the ice which deposited it came from the northwest and traversed the extensive limestone and shale areas of Manitoba. It is an unmistakable Keewatin drift.

So far as could be determined, it appeared to be identical with that great mass of bluish-black drift which makes up the bulk of the strong moraine ridge through which the Northwestern Railroad has cut its way, half a mile east of Hersey, Wis. This smooth ridge of thickened drift near Hersey marks an eastern border of a great Keewatin ice-sheet. Hersey is thirty-five miles southeast of the St. Croix River at Osceola, and hence Osceola should be almost in the line traveled by the Keewatin glacier which dumped Manitoban material near Hersey. The age of this grayish-black drift has not yet been conclusively established, but from what is known about it at the present time and the relations elsewhere in Wisconsin, Minnesota, and Iowa, it would seem best to assign it tentatively to the Kansan. Whether a pre-Kansan drift of similar Keewatin character and blackish color underlies it, as it does in some parts of Minnesota and Iowa, cannot yet be told.

The partially oxidized upper portion of this drift-sheet has been recognized in various portions of the St. Croix–Dalles quadrangle. The wagon road which leads from the Osceola bridge to the Minnesota upland country exposes in descending order the following section of older drift near the top of the river bank:

	Feet
1. Wash material including much from the Wisconsin drift ...	4
2. Gray-brown to yellow-brown calcareous till which breaks up into hard chunks ...	11
3. Stratified sand, light-colored above and rusty-brown below	$3\frac{1}{2}$
4. Dark-gray or bluish-gray till which is non-calcareous, apparently having been leached ...	2
5. Jordan sandstone.	

Above this section is a long slope with a rise of 35 feet to the highest river terrace. This old drift may therefore once have been fairly thickly covered with Wisconsin drift, since removed by the river.

One hundred pebbles averaging an inch in diameter were dug from the brown calcareous till (No. 2), and classified with the following result:

Fine-grained greenstones	29
Limestone	21
Granite (10 pink, 8 gray)	18
Gabbro-diorite	6
Quartz	4
Greenstone schist	3
Quartzite	3
Quartzose	3
Brown sandstone	3
Syenite	2
Mica schist	2
Red Lake Superior sandstone	2
Chert	2
Monzonite	1
Red porphyry	1
	100

The greenstones were largely of the dark Keewatin types. There seemed to be very little even among the gabbro-diorite group to suggest the Keweenawan lavas of the Lake Superior Basin. The glacier which deposited this drift received but little material from Lake Superior or from earlier Labradorean drifts.

Three miles east of Dresser Junction (T. 33 N., R. 18 W., Sec. 11, S.W. corner) the wagon road descending into a deep valley exposes a buff clayey till streaked through and through with silver-gray and bluish-gray portions like the typical banks of Kansan drift in Iowa. The calcareous material has been leached out of this oxidized portion of the till. The unaltered black drift was not seen. Fifty pebbles from this till were classified as follows:

		Percentage
Granite	12	24
Quartz	10	20
Fine-grained greenstones	8	16
Chert	5	10
Feldspar crystals	5	10
Syenite	3	6
Gabbro-diorite	3	6
Quartzite	2	4
Clay ironstone	1	2
Decayed igneous	1	2
	50	100

Pebbles in this exposure of the drift were small and scarce. They were mostly soft, showing evidence of much weathering and age. The classification of the pebbles collected shows the unmistakable Keewatin character of the drift even in the absence of limestone. The abundance of chert suggests the former presence of the calcareous element. This occurrence of western drift is three miles east of the limiting terminal moraine of the Keewatin glacier of the Wisconsin epoch, showing that this earlier Keewatin ice-advance was more powerful than the last.

The upper oxidized portion of this old Keewatin drift has now been recognized in limited sections in various other portions of the quadrangle. It has been brought to light in constructing the new railway spur from St. Croix Falls station down to the electric-power dam, and evidences of it have been seen on the Taylor's Falls side of the river. These occurrences suggest that if the entire region had not been buried beneath such heavy deposits of Wisconsin drift this supposed Kansan drift would be found to constitute an important sheet.

THE LOWER RED DRIFT

In the gully in which the true grayish-black till was first detected no pre-Wisconsin red drift was exposed to view, but in the next ravine to the north there was visible an intensely red, firmly consolidated till, or hardpan, upon which rested a rather ferruginous sand, and above that the fresher-appearing sand and gravel of Wisconsin age. A much better section is afforded by the wide, open ravine in the N.W. $\frac{1}{4}$, Section 15, Franconia ($1\frac{1}{2}$ miles southeast of Franconia). Near the head of this ravine the gray Keewatin drift of Wisconsin age is seen resting upon the red Wisconsin sands and gravels from Lake Superior and Labrador. Lower down toward the river is a bank of reddish-brown to pinkish-red sandy till which is bright carmine red at the top. Though a true red drift, it contains many limestone pebbles in some places and locally boils up briskly with acid. The Wisconsin red drift of this region is indifferent to acid and it is very seldom that a fragment of limestone is found within it. A sharply defined contact separates the hard red calcareous till from the overlying unconsolidated sands which undoubtedly belong to the Wisconsin red drift. At the top of the underlying red

till which becomes somewhat clayey at its upper surface, the writer found in 1907 small lumps of decayed vegetable matter and the remains of several tiny twigs. These were all in the uppermost inch of the red till. While there was no continuous layer of humus, these lumps and fragments of former branches were a decided feature of the contact. As this sort of material was found nowhere else in the red till or the sand above, it would seem to mark a true interglacial horizon. From the descriptions it appears to correspond closely with the humus horizon reported by Dr. Atwood and his class in 1904,[1] but which the writer has repeatedly sought but never been able to find, a fact due no doubt to later concealment.

Fifty pebbles from a calcareous portion of the lower red till were classified as follows:

		Percentage
Limestone	14	28
Fine-grained greenstones	9	18
Red Lake Superior sandstone	9	18
Granite (1 pink, 3 gray)	4	8
Red aphanitic	3	6
Jasper	2	4
Quartz	2	4
Chert	2	4
Quartzite	2	4
Red quartz porphyry	1	2
Gabbro-diorite	1	2
Mica schist	1	2
	50	100

The red rocks and the character of the greenstones show that this is clearly a Lake Superior drift, but the presence of so much limestone is surprising. Perhaps the ledges which furnished the limestone were covered by drift at the time of the Wisconsin ice-advance, so that the glacier failed to gather up much of this material. There does not seem to be very much black drift below the red at this point, since the rock appears quickly as one goes down the ravine.

Several of the cuts along the Northern Pacific Railroad, between Taylor's Falls and Franconia, show glacial deposits older than the Wisconsin red drift. A cut in the middle of the east line, Section 35, Shafer, exposes a rusty-looking gravelly deposit resting upon the Franconia sandstone. Though much obscured by talus, this deposit was seen to have a thickness of at least twenty feet. The upper part

[1] See *Jour. of Geol.*, XIII, 248.

of the cut is a bank of red Wisconsin drift. Fifty pebbles from this gravelly deposit under the Wisconsin drift, taken from a point six feet above the Franconia sandstone, were classified as follows:

		Percentage
Fine-grained greenstones	14	28
Red Lake Superior sandstone	7	14
Red quartz porphyry	4	8
Jasper	4	8
Brown sandstone	4	8
Granite	4	8
Gabbro-diorite	3	6
Quartz	3	6
Red diorite	2	4
Red aphanitic	2	4
Quartzite	2	4
Decayed igneous	1	2
	50	100

This is clearly a Lake Superior drift brought in by an ice-advance from the Labrador gathering-ground.

This lower red-brown drift is older than the Wisconsin red drift and younger than the grayish-black drift of supposed Kansan age. The nature of its occurrence within the St. Croix–Dalles quadrangle does not afford any very tangible clue to the age of this deposit. But it appears to be almost identical in lithological characteristics, degree of induration, and various minor peculiarities with the sheet of pre-Wisconsin red drift which forms the prominent moraine near the village of Hampton in central Dodge County, Minn. This is fifty miles S.S.W. of Osceola. In this moraine the hummocks still persist, though they have been much sharpened by slope-wash and are now peaked or conical in shape. From the amount of erosion and general appearance of this drift it seems perhaps best to assign it for the present to the Illinoian glacier from the Labrador center.

Similar pre-Wisconsin red drift overlies the grayish-black till in many cuts along the line of the Northwestern Railroad between Hersey and Baldwin, Wis. Some of these exposures show that a considerable interval of time elapsed between the retreat of the ice-sheet which deposited the grayish-black drift and the advance of the glacier which brought the red drift. The buff-weathered phase is present above the unaltered grayish-black till, and in some places this yellow oxidized till has been leached down five or six feet below

the contact with the overlying red till. Some cuts show a distinct erosion unconformity between the two drift-sheets.

At the present state of knowledge, the following drift-sheets have been recognized in the St. Croix–Dalles region:

1. A thin surface mantle of gray Wisconsin drift deposited by a glacier from the Keewatin center, as described in previous papers.

2. An upper red drift deposited by a glacier of Wisconsin age from Labrador, as similarly described.

3. A sheet of brownish-red to carmine-red sandy drift left by an ice-invasion coming from the Labrador center across the Lake Superior basin and extending as far to the south as the moraine at Hampton, Minn.; age consistent with Illinoian.

4. A sheet of dark grayish-black, calcareous, clayey till deposited by a vigorous advance of ice from the Keewatin gathering-ground and extending as far to the southeast as Hersey, Wis.; age probably Kansan, but still open to question.

"ROCK GLACIERS" OR CHRYSTOCRENES

J. B. TYRRELL
Toronto, Canada

In the number of the *Journal of Geology* for June, 1910, there is an interesting article by Stephen R. Capps, Jr., on "Rock Glaciers in Alaska" which must be of especial interest to all those who have lived in Alaska or in the Yukon Territory, and more particularly to those who have lived in the city of Dawson, for these latter will at once recognize the similarity of the rockslides described and illustrated by Mr. Capps to "the Slide" on the face of Moosehide Mountain at the north end of the town of Dawson, since the Slide is one of the outstanding and ever-present features of the landscape to every resident of that northern city.

The city of Dawson is situated on a swampy alluvial flat on the east bank of the Yukon River, just below the confluence of the Klondike River. About a mile to the northeast of it Moosehide Mountain rises to a height of 2,000 feet or more above the city, a spur of the mountain extending down to the Yukon River, and terminating the Dawson flat toward the north.

The mountain is composed of massive basic eruptive rock or diabase largely altered to serpentine, and cut by numerous jointage planes which allow the rock to break readily into angular fragments. Over the larger portions of the surface of the mountain the rock has been weathered and decomposed to a considerable depth, and has broken down into sand or rock flour, so that the natural slopes are consequently gradual and gentle. But on the southwest side of the mountain, directly overlooking the town of Dawson, there is a steep scarped face of bare rock several hundred feet in height, at the foot of which a talus of broken rock-fragments extends outward and downward toward the river. This talus extends so far outward from the foot of the scarp, and its lower portion has such a relatively gentle slope, that it has somewhat the appearance of having broken away suddenly from the side of the mountain; and consequently the early

miners attributed to the Indians a tradition that many, many years ago it had so broken away, and had buried an Indian village beneath it.

But it is not necessary to invoke any sudden landslide to account for this bare cliff and the great pile of loose rock at its base, since fragments of rock are even now constantly falling from the face of the scarp and adding to the size of the hill of rock-fragments below it.

FIG. 1.—The Slide at Dawson.

The conditions which would seem to have combined to produce this naked scarp and the wide-spreading talus of broken rock at its base are somewhat as follows:

The general surface of the Yukon Territory in the vicinity of Dawson is permanently frozen for a depth of from 100 to 200 feet, beneath which the rock is more or less thoroughly saturated with water. In some places, and often on hillsides, this underlying water forms channels for itself through the frozen rock and soil, and breaks out as springs, and at the foot of Moosehide Mountain, directly

beneath the *slide*, one of these springs issues from the fractured serpentine. In the early days of the city this spring furnished the best supply of water for drinking purposes available in the vicinity.

During the summer season the water from this spring flows freely from the rock and down through the talus slope at the foot of the hill, but in winter, when the thermometer often drops to 50 below zero,

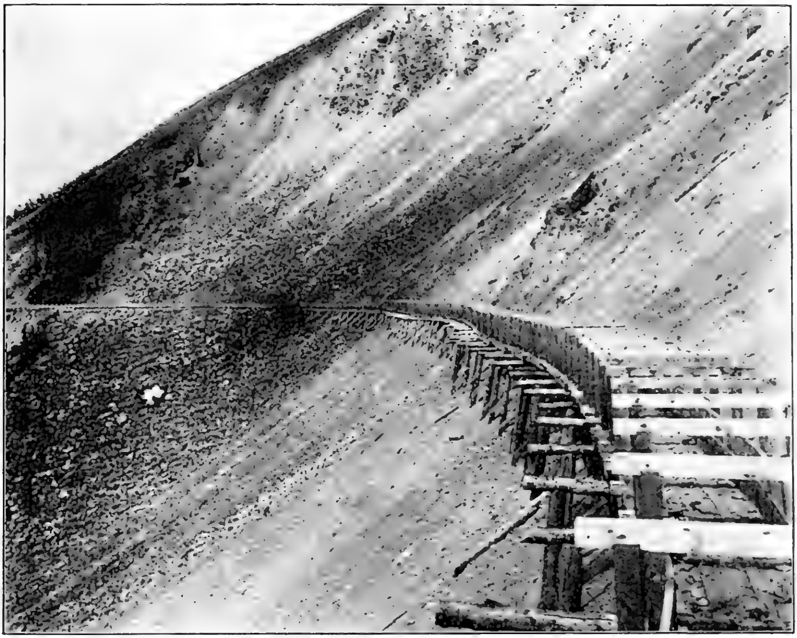

FIG. 2.—Upper part of the Slide at Dawson.

or lower, it freezes as it issues from the rock, or as it courses through the loose rock of the talus heap, and imbeds the broken fragments of rock in a matrix of clear, solid ice. At the same time loose pieces of rock are being constantly detached from the face of the hillside and dropped on this heap of rock-fragments lying below. In this way the heap of broken rock is being built up, and the weight of its higher side is being constantly increased. On account of this increase in weight, and also on account of the filling of the interstices between the rock-fragments with ice, there is a constant tendency for the pile of

loose rocks and ice to move downward and outward, and this tendency is increased in the spring and summer when the upper portion of the icy matrix becomes melted, so that the stones which were imbedded in it become loosened and slide downward over each other. This process of the breaking-down of the face of the almost vertical cliff and the growth and extension of the talus is constantly in operation year after year, so that the face of this hill of light-green serpentine always has the appearance of having just been freshly broken and the material at its foot of having just slidden from it, while the sloping field of loose rock below shows abundant evidence of having been recently moved to its present position.

We have here simply a northern modification of the conditions found on many hillsides where springs give rise to broken slopes.

In the *Journal of Geology*, XII (1904), 232, I described some springs which flow from the frozen hillsides in the Klondike and which in winter issue into the cold air, and are then almost immediately frozen into ice. During the course of the winter, these masses of ice may assume considerable proportions, and when they form on the roads or main lines of travel, they are often, on account of their smooth, sloping surfaces, the occasion of much inconvenience to the freighters and stage-drivers. In several instances they have also been known to break up in the floors of houses, and to fill the house with ice, just as they fill the spaces between the loose rocks in the heaps of talus. These frozen masses of spring water are, in the Klondike, locally known as "glaciers," but as this word was already fully preoccupied, I called them, on the suggestion of Professor T. C. Chamberlin, *chrystocrenes*.

The spring at the foot of Moosehide Mountain in Dawson forms one of these chrystocrenes, but instead of the water flowing out freely into the air, it flows into a detrital mass of broken rock and assists in gradually moving this rock outward from the foot of the mountain toward the Yukon River, which flows at its base.

I would suggest that the "rock glaciers" described by Mr. Capps may probably have been formed in the same way as the Slide at Dawson; that they are kept supplied with water flowing from springs in the sides of the hills; that this water becomes frozen into a mass of ice during the severe cold weather of winter; and that the ice, with

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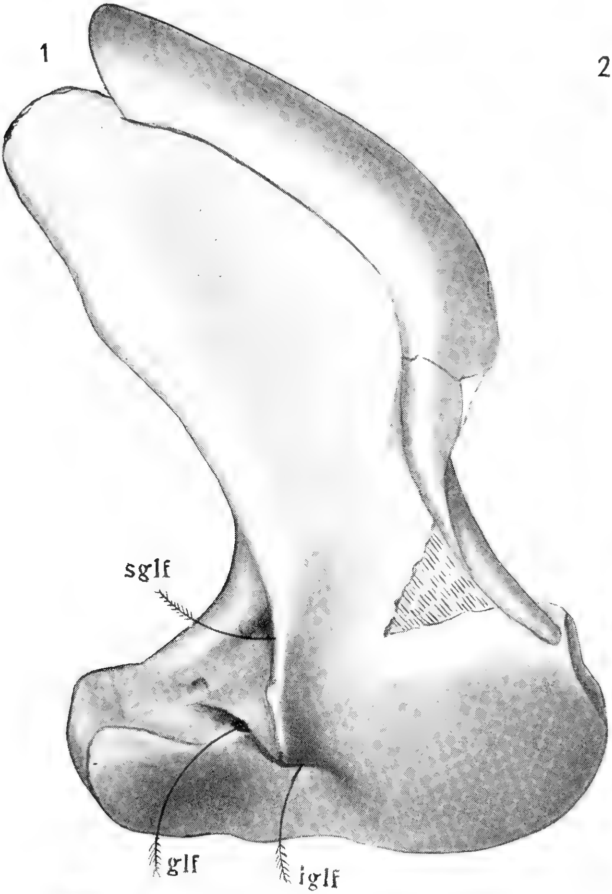

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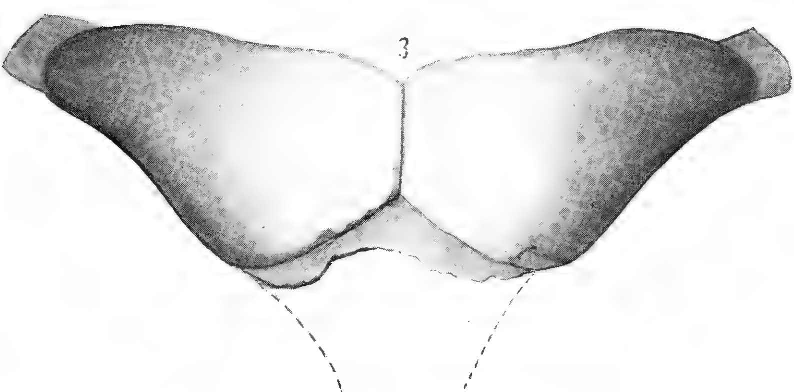


its contained fragments of rock, not only moves outward from the hills or mountains and down the valleys, but that when the upper parts of the ice melt under the influence of the warm weather in the spring, the rocks which were contained in it slide downward and form the concentric ridges which are so well shown in one of Mr. Capps's photographs.

The clear ice which constitutes the matrix for the mass of ice and stones in the talus is certainly not formed by the freezing of water during the warm weather of summer, when surface water is abundant, when streams are flowing in all the valleys, and when the temperature of the air often rises to 70° or even 80° F. It is equally certain that this icy matrix is formed during the winter, when, in the Klondike district, as well as in the interior of Alaska, the surface drainage is completely arrested, and the small streams are frozen to the bottom, and when the only water which reaches the surface is derived from springs with moderately deep-seated sources, though this spring water is quickly frozen into ice when it comes within the influence of the extremely low temperature of the overlying atmosphere.

The positions of these springs may readily be determined in winter time by the presence of chrystocrenes, which form more or less conspicuous mounds of ice elevated above the general snowy surface, but in the summer they are often very difficult to detect, for it may be impossible to distinguish between water derived from springs and that from surface drainage.

Therefore, the presence of the springs, and their possible significance in supplying ice to the talus heaps in order to enable these to move downward and outward more easily, would probably escape notice if investigations had been conducted exclusively in summer. Investigations conducted during the winter would probably prove the existence of springs behind these "rock glaciers," in which case they might be considered as chrystocrenes filled with broken fragments of rock.

ON A PECULIAR CLEAVAGE STRUCTURE RESEMBLING STRETCHED PEBBLES, NEAR ELLIJAY, GEORGIA[1]

W. C. PHALEN

INTRODUCTION

The subject of elongated or stretched pebbles has been treated in two articles by Mr. S. W. McCallie, state geologist of Georgia.[2] Both of the occurrences described are in Georgia, one of them, the first cited in the references below, being located in the vicinity of Ellijay, Gilmer County, about 75 miles north of Atlanta; the other 2½ miles southeast of Dahlonega, the county seat of Lumpkin County. Mr. McCallie's paper on the Ellijay occurrence may be summarized briefly as follows:

The stretched pebbles are chiefly confined to a belt less than one-half mile wide and about 15 miles long just west of the Louisville-Nashville Railroad and near the western margin of the crystalline rocks of the state. The beds containing the pebbles are in some places numerous. They vary from 1½ to 5 feet in thickness, and are always interbedded in mica schist. The pebbles in the different beds differ both in size and in degree of elongation. They are mainly found in a matrix of mica which, however, may be absent or nearly so, in which case the quartz pebbles may be welded together, requiring slight pressure to force them apart. Both quartz and feldspar pebbles are found, the former being the more numerous; the former also are greatly elongated while the feldspar pebbles retain more or less perfectly their original rounded shapes. The size, shape, color, and texture of the pebbles are next described, and the article closes with a description of thin sections of the pebbles. The title of Mr. McCallie's paper, "Stretched Pebbles from Ocoee Conglomerate," will serve to summarize sufficiently well his idea of the origin of the phenomenon.

[1] Published with the permission of the Director of the U.S. Geological Survey.

[2] *Jour. of Geology,* XIV (1906), 55–59; *ibid.*, XV (1907), 474–78.

During the past three summers the writer has had opportunity to study the metamorphic complex in the Dalton, Ellijay, and Dahlonega quadrangles at the northern edge of Georgia east of the Great Valley. Stretched pebbles,[1] so called, have been observed at various places in the first two areas mentioned. Among the localities visited and studied is that near Ellijay depot, as well as others not very far away from the town. As a result of these studies a possible different interpretation of this interesting phenomenon has been deduced. It is the object of this short sketch to present evidence for this interpretation of a phenomenon which, so far as the writer is aware, has never been observed elsewhere than in the southern Appalachians, or at least has never been described from any other region.

GENERAL GEOLOGY

The portion of the Appalachian Mountain belt near Ellijay probably consisted formerly of both sedimentary and igneous rocks. The region has passed through one or more periods of dynamic metamorphism as a result of compressive forces acting from the east or southeast. During this metamorphism and possibly since, the rocks were profoundly folded and faulted; simultaneously with and subsequently to these structural changes they have been altered and mineralized and as a result almost perfectly recrystallized. The erosion and weathering characteristic of the region as a whole, which followed the earlier forces, has left them in their present condition. The character of the rocks in the region varies widely from slightly metamorphosed slate to profoundly crushed and metamorphosed igneous and sedimentary rocks.

Location.—The first occurrence of "stretched pebbles" to be described is located near the town of Ellijay, the county seat of Gilmer County, near the confluence of Cartecay and Ellijay rivers. The "pebbles" may be found in a cut not more than 20 feet deep, on the railroad, 100 yards more or less north of the depot, almost opposite and also just beyond the new wholesale house of W. J.

[1] The term "stretched pebbles" is used for convenience in this and subsequent places. The writer's views as to the proper designation of these "pebbles" will be developed later.

Owenby & Co. This particular spot has been visited twice by the writer, first in the fall of 1907 and again two years later.

DETAILED GEOLOGIC RELATIONS

The cut is chiefly in the characteristic impervious surface or mantle clays of the region, and the "pebbles" are found in this clay, and in the slightly weathered country rock, found at the southwest end of the cut on the right side looking northeast. Those occurring in the country rock, however, are less perfectly developed than the others. The country rock is in the Great Smoky formation.[1] It is a greywacke and a weathered garnetiferous mica schist with the garnets largely altered to iron oxide. The schist is feldspathic. The rocks strike N. 20–45° E. and dip 50–60° S.E.

There are comparatively few or no signs of metamorphism in the rocks near Ellijay, which are extraordinary as compared with the general regional metamorphism, and such profound metamorphism as appears is generally quite local in development. At the location under discussion the rock has been so greatly crushed or subjected to such intense pressure that it does not break into massive blocks bounded by joint planes, but into long thin masses, resembling tapering lenses or stretched pebbles, overlapping when *en masse,* with excessive length as compared with their other dimensions. The illustration in Mr. McCallie's article[2] reveals the conditions well. At the south end of the cut these masses appear to be composed chiefly of quartz, and they will be found to crumble readily away from each other when removed from the ledge. When these quartz masses resembling stretched pebbles are thus separated, though some of the mica of the country rock falls away from them, considerable of it still adheres. Though many of these masses consist apparently of pure quartz, some of them contain or are largely made up of the micaceous portions of the country rock. All gradations between the two extremes may be observed. It is a fact, however, that the great bulk of the best

[1] The same units have been chosen for mapping in the Ellijay quadrangle as were adopted by Keith in the Nantahala area to the north ("Nantahala Folio, No. 143," *U.S. Geol. Survey,* 1907). Of course the same scheme has not been adopted in its entirety, for the obvious reason that some of the more marked lithologic types die out in passing to the southward.

[2] *Journal of Geology,* XIV (1906), 56.

examples of the "pebbles" are composed chiefly of quartz, excepting those produced from vein quartz to be described directly.

Traversing the country rock in all directions are quartz veins, true chemical segregations. Though formed subsequently to the rock in which they are found, they antedate, in this restricted locality, the period of metamorphism in which the pebbles described above were produced, for the reason that the structure has been produced in the quartz vein itself. Indeed it is from such material that the most perfect "pebbles" were obtained (see Fig. 1). The quartz veins in the railroad cut vary from a fraction of an inch up to 6 inches or more in thickness. Toward the northwest end of the cut under discussion, and just before the gradual curve to the right begins, will be found the best exhibition of the "pebbles." In the fall of 1907 one of the quartz veins could be traced fairly well across the cut, which at the time was thought to have furnished the bulk if not all of the best specimens. This evidence, however, is not at all conclusive at the present time, for on a more recent visit in the fall of 1909, this tracing could not be made at all, on account of slides in the clay in the cut. That the vein quartz has furnished the material for many of the lenses of "pebbles," however, can be shown from the specimens collected at the earlier visit, in which the gradation from the latter into the former is well brought out (see Figs. 2 and 3). In such hand specimens the quartz lenses may be picked out and replaced in their former positions, the whole appearing as a single solid mass when bound with an elastic band. Specimens were col-

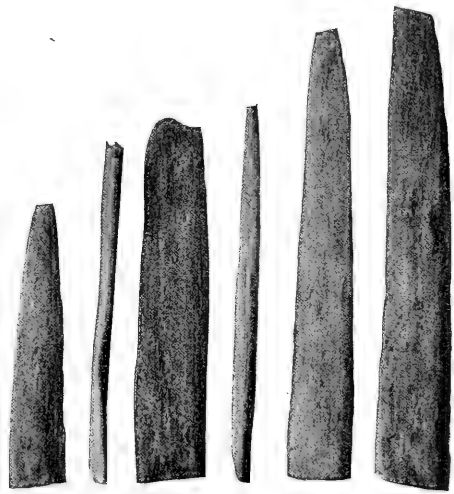
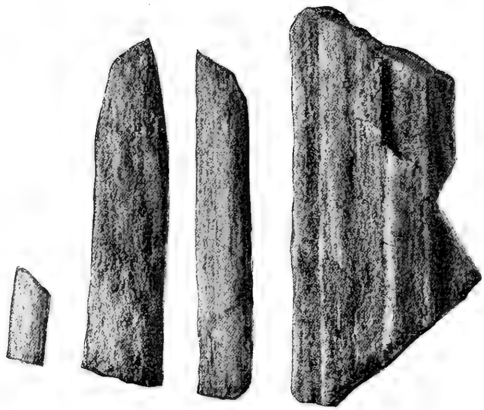


FIG. 1.—A group of quartz lenses, resulting from pressure on vein quartz. Ellijay, Gilmer County, Georgia.

lected showing varying stages in the transition from the unfractured massive vein quartz to those in which the quartz pebbles were fairly well developed. Such specimens though less perfect examples of the structure itself are nevertheless instructive in that they show the



1 2 3 4

Fig. 2

Fig. 3

Fig. 2.—Group of quartz lenses. Lenses numbered 1, 2, and 3 have been separated from 4 and may be replaced in their former positions.

Fig. 3.—A bundle of imperfect lenses. The arrow indicates a lens about to break off.

intermediate steps in the transition of the massive rock to the lenticular or stretched pebble-like phase, and one method by which the latter may be formed.

OTHER OCCURRENCES

On the road which leads directly north from Ellijay up Ellijay River there is another occurrence of the structure (for such it may be regarded) described near Ellijay depot, about a mile and a quarter north of the town and about a quarter of a mile south of the road forks.

The rocks here strike N. 20–25° W., though the general strike of the region is to the east of north. Like the rocks at Ellijay depot, the country rock here may be classed as a feldspathic mica schist, in which there are secondary feldspar phenocrysts, badly weathered. The rock probably was arkose originally. As at Ellijay depot, there are associated quartz veins which here however postdate the metamorphic processes which produced the pebble-like structure, as the vein material does not show any particular tendency to break into lenses as at Ellijay depot. The phenocrysts of feldspar already referred to have probably formed since the crushing took place, as during their development they have pushed away the surrounding matrix which now curves about them. This latter hypothesis to the writer is a more plausible assumption than that the crushing processes have failed to affect them, for there is no reason to suppose that they would resist the crushing action more effectively than quartz. The joint planes in the rock cut squarely across the pebble-like quartzes and are therefore in part at least of later origin. The broadest band in which quartz lenses appear is fully 15 feet thick. A short distance farther up the hill are two thinner bands showing the phenomenon equally well with the 15-foot band, and the intermediate beds exhibit it, though less perfectly. Such highly metamorphosed bands are fairly common in this general region and good examples have been observed and specimens showing the structure collected north of the head of Kells Creek within the Ellijay area.

It is not so easy here to disprove the former existence of original true quartz pebbles and no attempt will be made to do this. It will simply be pointed out that the similarity of the occurrences to that near Ellijay depot is noteworthy, and that, as in the latter case, another hypothesis for the origin of the quartz masses is not only possible but probable.

DETAILED DESCRIPTIONS

It was thought that a study of thin sections of the rock showing the pebble structure might throw some light on the origin of the phenomenon. The results, however, are somewhat inconclusive. The sections of the "pebbles" do show evidence of profound crushing, but then either crushed true pebbles or vein material would exhibit similar features in thin sections. Instead of the crystalline outlines

characteristic of ordinary uncrushed vein quartz in thin sections (see Fig. 4), the sections are fine-grained mosaics with crystallographic boundary planes entirely absent (Fig. 5). Therefore the most important evidence of derivation from former vein material is absent. Even all signs of internal strain are lacking for the reason that the quartz like all the other rocks of the region has undergone almost perfect recrystallization, that is, molecular readjustment to

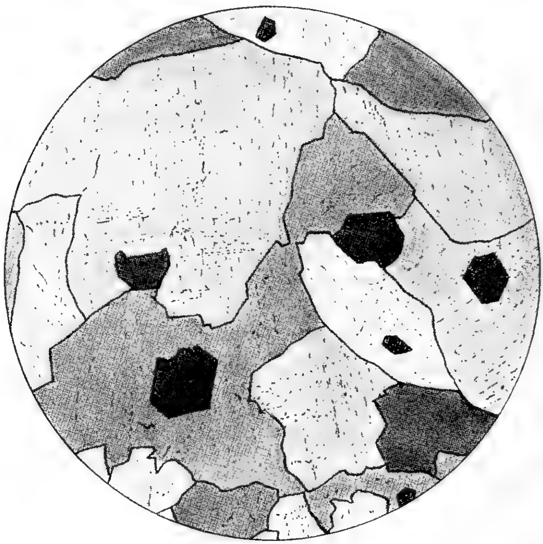


FIG. 4.—Normal structure in vein quartz. From the report of Waldemar Lindgren on the "Gold Quartz Veins of Nevada City and Grass Valley Districts, California." In *Seventeenth Annual Report, U.S. Geological Survey,* Part II (1896), Pl. IV, Fig. *a,* opposite p. 132.

the surrounding conditions. The actual tracing of the "pebble" structure, however, into the original quartz vein material is sufficient evidence for another explanation of the phenomenon.

The results of the examination of the thin sections are given below.

Several thin sections cut in various directions from the quartz masses were studied in polarized light under the microscope, to determine if possible how deformation took place. These sections were cut as follows: (1) normal to the direction of elongation of the pebbles; (2) parallel to the direction of elongation and to the major

axis of the approximately elliptical cross-section; (3) parallel to the direction of elongation and to the minor axis of the approximately elliptical cross-section.

The sections are all alike in showing the quartz masses to be essentially mosaics of irregularly shaped granular interlocking particles. In a word, the microscopic structure is typically that of crushed and recrystallized quartz. In the first set of thin sections

FIG. 5.—Micro structure of crushed vein quartz from near Ellijay, Ga. The lack of crystallographic boundaries is apparent.

examined, namely, those cut normal to the direction of elongation of the masses, the grains show dimensional, but not crystallographic parallelism. The longer axes of the grains, as would naturally be supposed, are parallel to the major axis of the elliptical cross-section. This may be and quite likely is due to deformation, but there are no evidences of deformation in sections cut parallel to the direction of elongation of the quartz masses, as might naturally be expected. If due to deformation producible by pressure normal to the direction of flattening, all evidence of internal strain, usually evidenced by wavy extinction, has disappeared, but this might readily be brought about by recrystallization. The perfect interlocking of the grains is

evidence of recrystallization. The molecular readjustment necessary to obliterate all traces of strain may have occurred while the rock was deeply buried, for it is almost certain that many of the phenomena associated with the rocks of the region could only have been produced while under very heavy load, i.e., while deeply buried, or subjected to great pressure, or both. But it seems that recrystallization by solution and redeposition is as adequate and as safe an explanation. That the rocks contained water is certain. The presence of muscovite and biotite as secondary minerals, and the evidences of the sedimentary origin of the rocks, all point to the former presence of water. The amount of water present may have been small, as the presence of large quantities of water to bring about such molecular changes as postulated above is not essential.[1]

In sections cut parallel to the length of the quartz masses, there are also evidences of crystallographic continuity, the larger part of the sections extinguishing in a given position. Finally in all the sections studied cracks were observed running parellel to the major axes of the cross-section and also parallel to the length of the quartz masses.

CONCLUSION

As a result of the studies made by the writer, it is concluded that there is no necessity for assuming the former presence of original quartz pebbles to produce the pencillate or pebble structure, or lens-shaped masses of quartz described above, for, as pointed out, the more perfect examples of the structure have been found resulting from quartz veins. That elongations in true quartz pebbles may occur and the results exactly resemble the structures figured above, is so obvious as hardly to necessitate mentioning here. The structure is regarded as essentially due to a peculiar cleavage combined with flow cleavage (recrystallization). It is quite likely that it may be produced in any rock and the simpler, the more resistant, and the more homogeneous the material, perhaps the more perfect the resulting structure. Such structures on a much larger scale have been observed by Mr. Arthur Keith of the U.S. Geological Survey, a few miles west of Canton, Ga. They are figured in the accompanying illustration (Fig. 6). The country rock here is a talc schist, and

[1] C. K. Leith, "Rock Cleavage," *Bull. U.S. Geol. Survey, No. 239* (1905), 69.

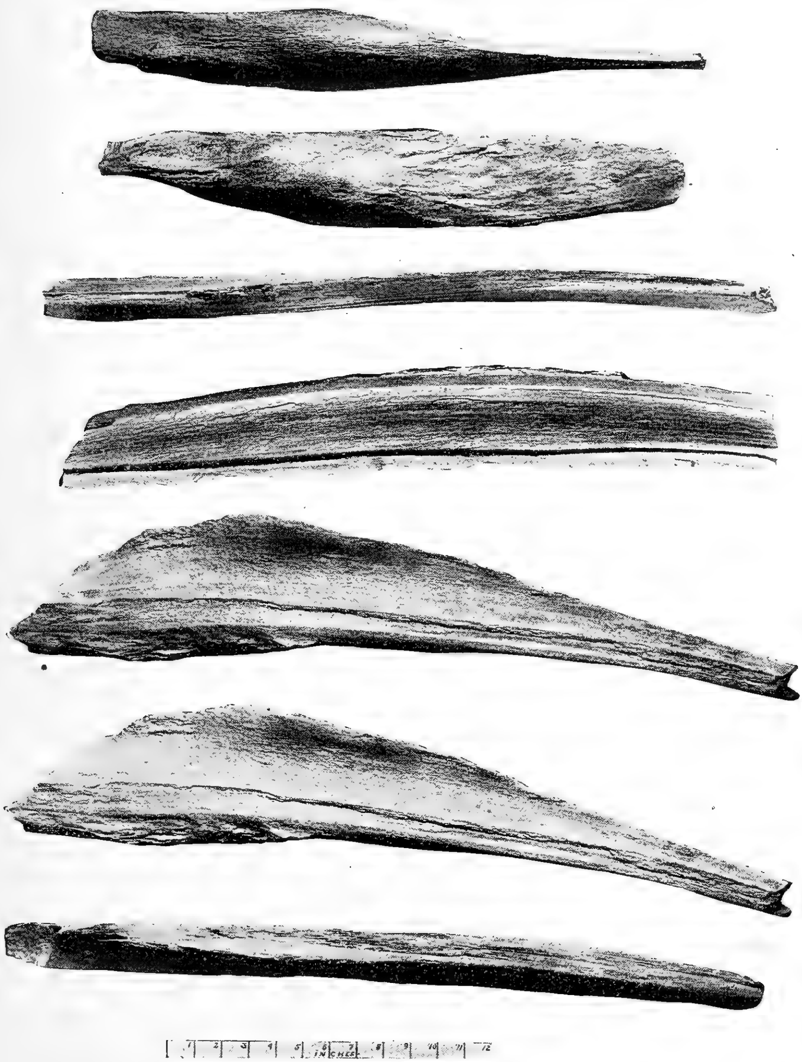


FIG. 6.—Elongated or lens-shaped masses of quartz, occurring in talc schist. Photograph of specimens collected by Mr. Arthur Keith, U.S. Geological Survey, near Canton, Georgia.

the elongated lens-shaped masses are essentially made up of quartz with an outer covering of the schist. They measure nearly 3 feet in length, with a breadth of 2 to 4 inches and a thickness of 1 to 2 inches. So far as appearances go, they closely simulate on a much larger scale the smaller masses collected near Ellijay. They cannot by any stretch of the imagination be regarded as stretched or deformed bowlders. Pogue[1] has figured and described almond-shaped masses of mashed acid coarse tuff from Davidson County, North Carolina. The rock, according to this writer, has undergone a moderate amount of compression and now projects above the ground surface in lenticular or almond-shaped masses 20 feet long, 10 feet high, and 5 feet thick at the base. They are distributed in groups and often scores may be seen in alignment following the trend of a tufaceous belt. It has occurred to the writer that Pogue's almond-shaped masses may be of the same nature as the structure observed near Ellijay, but on a gigantic scale. In conclusion, it is desired to emphasize the view that the Ellijay occurrences are purely structural phenomena producible in varying degrees of perfection in almost any rock, independent of original pebbles, and liable to occur in any region of intense metamorphism.

[1] *Am. Jour. Sci.*, XXVIII (September, 1909), 224.

Reviews

Soil Fertility and Permanent Agriculture. By CYRIL G. HOPKINS. 8vo. Pp. 23+653, ill. 14. Boston: Ginn & Co., 1910. $2.75.

This volume is a "summons and a challenge." It is dedicated to "The Association of American Agricultural Colleges and Experiment Stations, the rightful guardians of American soils." It is addressed to farmers and students of agriculture, who "have at least as good intellects as other classes of people." It is a book not written for entertainment, but to be studied, and it is well worth studying.

Part One has four chapters, largely foundation facts of chemistry; three chapters on soil formation, classification, and distribution; two chapters on soil survey and soil analysis by the United States Bureau of Soils, an excellent summary, with instructive maps; and three chapters on crop requirements in the principal soil compounds as plant foods. Part Two consists of six chapters devoted to permanent agriculture, showing the rôle of limestone, nitrogen, and phosphorus, the significance of rotation, and theories concerning soil fertility. Part Three is an excellent résumé of the best soil investigations by culture experiments, as carried on at Rothamstead, England, and at the leading American experiment stations, Pennsylvania, Ohio, Illinois, Minnesota, and others. Part Four is devoted to studies of various fertility factors; and the volume closes with an appendix of valuable statistical and other data ancillary to the text.

In the introduction the author says truly: "The most important material problem in the United States is to maintain the fertility of the soil, and no extensive agricultural country has ever solved the problem." And again, "If the art of agriculture has ruined the land, the science of agriculture must restore it, and the restoration must begin while some farmers are still prosperous, for poverty-stricken people are at once helpless, and soon ignorant, and poverty makes no investments."

The book is filled with the results of scientific studies, showing the elements removed from the soil by the growing crops, and the quantity there to be removed; showing the results of various fertilizers, and of various systems of rotation; showing that the key to permanent agriculture lies in phosphorus and decaying organic matter; and that good farming consists in an accurate bookkeeping with the soil.

It is shocking to learn that all the known phosphate deposits in the world will last at best only 250 years at the present rate of consumption; that America now furnishes two-thirds of the world's supply and sells half of it to foreign lands; while it would require our entire production of phosphates upon our own soil to give back to the soil what our corn crop alone takes from it.

The author is to be congratulated on producing a strong book in a very vital field. Its influence should be constructive in a high degree.

J. PAUL GOODE

Epitome of the Geology of New South Wales. By E. F. PITTMAN. Circular No. 9. Sydney: Mining and Geological Museum, 1909. Pp. 9, with geologic map.

This little pamphlet giving in a very brief, condensed form the principal features of the geology of this large Australian province has just come to the reviewer's attention. Those who frequently have occasion to familiarize themselves with the salient points in the geology of various portions of other continents often have longed for a series of just such outlines as this. To pick the desired information from separate volumes of a long array of standard geologic reports is a tedious and time-consuming task. A good map and the essential facts of a far-away country brought together and made available for ready use is a boon to every geologist who may have occasion to refer to that region. Now that geological studies are world-wide it is to be hoped that other countries and provinces will follow the example of New South Wales.

R. T. C.

Life and Letters of Josiah Dwight Whitney. By EDWIN TENNEY BREWSTER. Boston: Houghton Mifflin Co., 1909. Pp. 411, 18 illustrations.

In this biography the curtain is drawn aside and the reader is introduced intimately to one of the most conspicuous of the pioneers of American geology. When Whitney commenced his field work as an assistant on the first geological survey of New Hampshire in 1839, almost the whole of the United States was geologically an unknown land. The story of Whitney's life as it is unfolded in this book carries with it much of the history of several of the early surveys in which he took a leading part. These are the survey of the Lake Superior region (1847–50) which turned him from chemistry, toward which he had been preparing himself, to geology, and the Iowa State Survey, to which he was appointed in 1855 and which brought him

into active service in Wisconsin and Illinois as well. In 1854 appeared Whitney's *Metallic Wealth of the United States* which was the most notable work on the subject at the time.

With his fortieth year comes the end of the first of the three periods into which his life naturally divides itself. He has been by turn chemist, mining expert, geological surveyor, but never the single head of a survey. With the appointment as organizer and chief of the California Survey he is geologist and his own master.

The years in California were a period of ceaseless activity for Whitney, for the difficulties confronting this young survey in a new state of the dimensions of California were great. It was at this time that the youthful Baron von Richthofen came to California to study volcanic phenomena and became associated for a short time with the state survey. Out of this developed the lifelong friendship between these two geologists. Richthofen's geological survey of China was Whitney's idea, and the Baron often used to recall the New Year's Eve between 1867 and 1868 when he and Whitney sat up all night and planned the China Survey.

In 1874 the California Survey came to an end. Its termination apparently was due to a variety of causes. The survey had been from the first the project of a small group of enlightened persons, not the response to any popular demand, and its function and work were but poorly appreciated. In addition the survey earned the ill-will of many promoters, especially the oil companies, by steadily minimizing, with perhaps unnecessary directness and emphasis, the commercial possibilities of the California oil fields. Such a combination of causes—the bad financial status of the state, a general lack of insight and appreciation of scientific work by its influential people, the opposition of unscrupulous promoters, and an unfortunate cavalier tone and frequent want of tact displayed by the state geologist which stimulated general antagonism from the mining interests and from the governor—led to the final wreck of the survey.

The California Survey was in a way the pathfinder for the U.S. Geological Survey which was organized under King, Whitney's protégé, in 1879. The first director and some of his best-trained associates had received their geological training and field experience under Whitney. The methods of field work and topographic surveying adopted in California were later transplanted in the larger organization. The California Survey first shook the tree of which the federal survey has gathered up most of the fruit.

After such active pioneer field work and incessant travel for so many years, Whitney settled down for the latter part of his life as Sturgis-Hooper professor at Harvard. He did only a limited amount of teaching to small

advanced classes, but though his pupils were not numerous, they were picked men, and the list of those who were trained under him includes not a few of the leading geologists of the country today.

The story is chiefly told by his letters to his favorite brother, William Dwight Whitney—letters which reveal the man without the reserve which usually accompanied hm, and which portray in a very graphic and vivid style much of the history of early geological exploration in this country.

R. T. C.

Iowa Geological Survey, Vol. XIX, Annual Report, 1908. With Accompanying Papers. Des Moines, 1909. Pp. 806, 22 plates, 117 figures.

Coal is the principal topic of this volume. Besides the *Seventeenth Annual Report of the State Geologist*, Professor Samuel Calvin, it contains the following papers: "Mineral Production in Iowa in 1908," by S. W. Beyer, pp. 1–20; "Coal Deposits of Iowa," by Henry Hinds, pp. 21–396; "Fuel Values of Iowa Coals," by F. A. Wilder, with analyses of Iowa coals by James H. Lees and A. W. Hixcon, pp. 397–519; "History of Coal Mining in Iowa," by James H. Lees, pp. 521–88; "Coal Statistics," by S. W. Beyer, pp. 591–97; "General Section of the Des Moines Stage of Iowa," by James H. Lees, pp. 598–604; "The Carboniferous Section of Southwestern Iowa," by George L. Smith, pp. 605–57; "Bibliography of Iowa Coals," compiled by James H. Lees, pp. 659–87; "Peat Deposits in Iowa," by S. W. Beyer, pp. 689–730; "Bibliography of Iowa Peat," compiled by James H. Lees, pp. 731–33; "Flora of Northern Iowa Peat Bogs," by L. H. Pammel, pp. 735–77.

R. T. C.

Radioactivity and Geology. An Account of the Influence of Radioactive Energy on Terrestrial History. By J. Joly. Pp. 287, pls. 6, figs. 4. New York: Van Nostrand Co., 1909.

The discovery of radioactivity has opened the way for quite a new conception of many geologic phenomena. Fresh light has been thrown upon obscure and difficult problems, old explanations have been weakened or displaced, and alternative hypotheses have been framed to explain various phenomena. Radioactivity when first discovered appeared to have its chief interest in the domain of the physicist and the chemist. How vital a rôle it may yet prove to play as an active geologic agent, how wide a range of geologic processes it may yet be found to enter as a decisive

factor, has been brought out with a large measure of fulness in this new work by Joly. The first two chapters are chiefly an exposition of radioactivity from the historical, physical, and chemical standpoint. They lay the foundation for the geologic studies and the applications which follow. The third chapter gives data upon the occurrence and distribution of radium in the earth's surface materials and leads on to others in which some of the author's more notable inferences and speculations are set forth.

Radioactivity is made to appear as an agency of prime importance in the variations and fluctuations of underground temperature. A study based upon the rocks and underground temperatures of the St. Gotthard and Simplon tunnels is thought to show a distinct connection between the radioactivity and the temperature gradients in the earth. With less plausibility, the tendency of mountain ranges to develop along belts of thick sedimentation is assigned to the radioactivity of the buried sediments and the supposed consequent heating. Pushing the view still farther, the author even endeavors to explain the exigeant phases of the mountain structure of the Alps, such as the peculiar overlapping pile of recumbent folds as set forth by Lugeon, Schmidt, and others, by localized radioactive heating of the strata during the process of folding, and by a resulting upward shifting of the geotherms which is thought to enable the folded sediments above to be carried northward by the thrusts while the synclinal troughs beneath are becoming anchored in the growing viscosity of the medium. The idea is suggestive, but it lays a heavy tax on the new agency.

The chapter on "Radioactivity and the Interior of the Earth" and the one following set forth the possibilities of radioactivity as a more profound source of the thermal energy of the globe; however, the author believes that the radium of the earth is largely concentrated in the outer 12 to 15 kilometers of the crust.

Strutt has estimated the age of various sedimentary beds by determining the amount of helium which they contain and comparing this with the rapidity with which this gas is developed from the radioactive materials present. He reaches the conclusion that the Carboniferous must date back above 140,000,000 years, as a minor limit, and the Huronian probably 400,000,000 years. Though a most enthusiastic supporter of the great importance of radioactivity as a geologic agent and as a clue to the unraveling of geologic history, Joly is inclined to place greater reliance upon estimates of the age of the earth based upon denudation, and upon the saltness of the sea, than upon those based upon the radium and helium content of the sedimentary deposits.

The book bristles with new suggestions, and as such is a contribution of stimulating value. Necessarily, however, many of the conclusions thus put forth somewhat tentatively must be received with reserve.

R. T. C.

The Whitehorse Copper Belt, Yukon Territory. By R. G. McConnell. Canada Department of Mines, Geological Survey Branch, 1909.

These very interesting copper deposits are located in the southern part of the Yukon territory, extending along the valley of the Lewes River for a distance of about twelve miles. The rocks of the district are limestones probably belonging to the Carboniferous period, cut by three sets of intrusions of Mesozoic age. Of these the second set, consisting of granites and granodiorites, are economically important. Overlying these rocks are basalt flows belonging to the Tertiary, and glacial silts and bowlder clays.

The ore deposits are all contact metamorphic in origin, chiefly in the limestone along its contact with the granite. Two types of deposits are noted, the magnetite ore bodies and the siliceous ore bodies. In the former, the chief minerals are magnetite, bornite, chalcopyrite, serpentine, calcite, clinochore, rarely pyrrhotite and sphalerite. In the latter, associated with the ore minerals, bornite and chalcopyrite, are andradite, augite, tremolite, actinolite, epidote, and calcite. The granite itself is mineralized for some distance from the contact, the same minerals being developed as in the limestone. The deposits are peculiar in having bornite as the principal ore mineral, and in having little or no secondary sulphide enrichment. The values in copper range from 3.20 per cent to 12.90 per cent, the richest being from the Valerie Mine, in which bornite is absent and chalcopyrite is the only known copper sulphide present.

E. R. L.

Eigh'eenth Annual Report of the Bureau of Mines, Ontario, 1909. Vol. XVIII, Part I.

The Report contains the following papers: "Statistical Review, by Thos. W. Gibson, Deputy Minister of Mines, pp. 5–78; "Mines of Ontario," by E. T. Corkill, Inspector, pp. 79–140; "Iron Ranges of Nipigon District," by A. P. Coleman, pp. 141–53; "Iron Range North of Round Lake," by E. S. Moore, pp. 154–62; "Black Sturgeon Iron Region," by A. P.

Coleman, pp. 163–79; "Bog Iron on English River," by E. S. Moore, pp. 180–95; "Geology of Onaman Iron Range Area," by E. S. Moore, pp. 196–253; "Iron Formation of Woman River Area," by R. C. Allen, pp. 254–62; "Lake Abatibi Area," by M. B. Baker, pp. 263–83; "Lake Ojibway; Last of the Great Glacial Lakes," by A. P. Coleman, pp. 284–93; "Classification and Nomenclature of Ontario Drift," by A. P. Coleman, pp. 294–97.

E. R. L.

The Yakutat Bay Region, Alaska. U.S. Geological Survey Professional Paper 64. 1909.

Physiography and Glacial Geology. By RALPH S. TARR; and *Areal Geology*, by RALPH S. TARR and BERT S. BUTLER. 183 pages.

Yakutat Bay lies about forty miles southeast of Mount St. Elias, and is the only break in a straight coastline of about three hundred miles. To the west is the great Malaspina Glacier, while numerous large glaciers occupy the region about the head of the bay. Of these the Hubbard Glacier is probably the finest example of a tidal glacier on the North American continent. The mountain region northward from the bay is described as a vast snow-covered area from which hundreds of angular peaks project, while the valleys are flooded with ice, giving rise to an ice drowned topography, from which valley glaciers extend toward and in some cases to the sea. The condition is so different from normal valley glaciation that a special name, "through glacier," is proposed. The glaciers are in a stage of retreat which has apparently been in progress for a considerable length of time. A marked change, in the nature of paroxysmal thrust affected at least four of the glaciers, mainly in the ten months preceding June 1906. As interpreted by the author, this was probably due to the shaking-down of great avalanches of snow onto the upper part of the glaciers by the earthquake of 1899. The description of the glaciers, glacial erosion, and glacial deposits takes up the greater part of the volume.

The rocks of the district are almost barren of fossils and have been subjected to profound disturbance. Four distinct groups are recognized, a complex series of granites, gneisses and schists, the Yakutat group of conglomerate shale and sandstone, probably Mesozoic, Tertiary sandstones, shales and clays, and glacial gravels.

E. R. L.

Reports on a Portion of the Algoma and Thunder Bay Districts, Ontario, by W. J. WILSON, and *On the Region Lying North of Lake Superior between the Pic and Nipigon Rivers, Ontario*, by W. H. COLLINS. Canada Department of Mines, Geological Survey Branch, 1909.

In the region covered by the first report the rocks are chiefly Laurentian, consisting of granites and gneisses. These are interrupted in considerable areas by hornblende and biotite schists with diabase dikes, which are classed as Keewatin. Microscopic descriptions of these rocks made by G. A. Young are given. In the north of the region are nearly flat-lying dolomitic rocks classed as Cambro-Silurian and Silurian. A list of fossils from these formations identified by J. F. Whiteaves is appended.

The entire region covered by the second report is composed of pre-Cambrian rocks, all of which are crystalline except in the west, where comparatively unaltered sediments are to be seen. According to lithological characters the rocks are placed in four groups: (1) Laurentian, an intimate association chiefly of granites and gneisses of various sorts; (2) Keewatin, dark green, gray, or black schists largely eruptive in nature, and sheared porphyries containing much secondary chlorite and pyrite; (3) Keweenawan, brick-red dolomites; and (4) eruptives, hornblende and eleolite syenites, diorite, pegmatites, and diabases.

Minerals of economic importance occur in considerable variety but few deposits of valuable extent have been found.

In both reports considerable attention is given to the routes followed and the rock exposures studied.

E. R. L.

The Coal Fields of Manitoba, Saskatchewan, Alberta and Eastern British Columbia. By D. B. DOWNING. Canada Department of Mines, Geological Survey Branch, 1909.

This report is a concise statement of the area and probable contents of the various coal fields of the middle portion of Canada. There are three important coal-bearing formations, all belonging to the Cretaceous period and separated by shales of marine origin. These are the Kootanie, the Belly River or Judith River (Montana), and the Laramie. The character of the coal ranges from lignite to anthracite, the anthracite area being that of the Cascade basin. The areas in which coal is to be found are described briefly; analyses already published are collected in the form of tables and selected analyses of other North American and foreign coals are added for comparison.

E. R. L.

Petrological Abstracts and Reviews

Edited by ALBERT JOHANNSEN[1]

Clarke, F. W. "Analyses of Rocks and Minerals from the Laboratory of the U.S.G.S.," *Bull. U.S. Geol. Survey No. 419*. Pp. 315. 1910.

Bulletins 220 ("Mineral Analyses") and *228* ("Analyses of Rocks") are combined in this edition and brought up to date. The conventional form of stating analyses is retained and the same method of treatment is followed. New Analyses: igneous rocks 56; sandstones, cherts, and sinters 21; carbonate rocks 39; slates and shales 3; soils, etc., 21; minerals 93. With these additional analyses there is a reduction of 169 pages which gives a large amount of valuable information in a small, compact bulletin.

Charles J. Hares

Dale, T. Nelson. "The Granites of Vermont," *Bull. U.S. Geol. Survey No. 404*. Pp. 133, pls. 5. 1909.

This work is a companion bulletin to those on the granites of Maine (No. 313), and of Mass., N.H., and R.I. (No. 354). Its method of treatment is both scientific and economic.

Part I. Geographically the granitic areas extend in a northeasterly direction between the central Green Mountain axis on the west and the Connecticut River on the east for almost the entire length of the state. The granites are of three types: (1) biotite granite, as that at Barre; (2) quartz monzonite, as that at Bethel; and (3) hornblende-augite granite—the "olive-green syenite" of Daly—as that from Mount Ascutney. The age of the Ascutney granite is placed as post-Carboniferous or pre-Cretaceous, that on the west side of Green Mountain as late Devonian or Carboniferous, and the traversing dikes as possibly Triassic. The author's conclusions are based largely on the works of Richardson and Daly.

Special points emphasized are: double sheeted structure, that is, a structure with horizontal jointing; compressive strain, which is illustrated by the elliptical shape assumed by the drill holes; schist inclusions; con-

[1] Abstracts may be sent to Albert Johannsen, Walker Museum, The University of Chicago, Chicago, Ill.

tact metamorphism (at Bethel the magma under pressure sent out stringers into the wall rock; at Barre, the constituent elements, quartz, feldspar, biotite, pyrite, apatite, etc., were injected as heated vapors along the cleavage foliation); orbicular texture in granite at Bethel—the nodules occur in sheets parallel to the flow structure and the major axes of the disks are parallel to the micaceous flowage bands; and delimonitization on the under side of the sheets of granite.

Part II, while chiefly economic, touches on the general geology of the areas, gives petrographical descriptions of rocks, and economic details of the quarries. The work concludes with a bibliography of the literature on granites and a glossary of rock and quarry terms.

CHARLES J. HARES

DALY, REGINALD A. "Average Chemical Compositions of Igneous-Rock Types," *Proc. Amer. Acad. Arts and Sci.*, XLV (1910), 211–40.

Using Osann's "Beiträge zur chemischen Petrographie" and a few other sources, the average chemical composition of 98 principal igneous-rock types (excluding ascitic dikes) has been calculated. The results are shown in a table which also gives the averages for the same rocks regarded as anhydrous. These averages are of use in showing the chemical "center-points" in Rosenbusch's classification, the one in general use by the makers of geological maps. The averages furnish one of the bases for finally calculating the "average igneous rock." The relative uniformity in the soda percentage of the more abundant types is specially noted in its bearing on the origin of oceanic sodium and, therewith, on the problem of the age of the earth. The striking similarity of the average granite analysis to the average analysis of the base (ground-mass) in augite andesite, and the equally close resemblance of the average diorite analysis to the arithmetical mean of average basalt and granite are illustrated. The table of averages shows that the effusive rocks are more salic than the corresponding plutonics, helping to prove the justice of Rosenbusch's primary subdivision of igneous rocks into deep-seated types and surface lavas. The difference is explained genetically. Other special points in classification are noticed. The essential identity of the averages for pre-Cambrian and post-Cambrian granites is referred to the "anchi-eutectic" nature of the type.—(AUTHOR'S ABSTRACT.)

DALY, REGINALD A. "Origin of the Alkaline Rocks," *Bull. Geol. Soc. America*, XXI (1910), 87–118.

No alkaline province can be described as free from subalkaline eruptives, especially those of basaltic or granitic types. Emphasis is laid on the indisputable fact that the visible volume of all alkaline rock bodies is a very minute quantity as compared with the visible volume of subalkaline eruptive bodies. An inductive study shows that most alkaline rocks cut thick masses of limestones, dolomites, or other calcareous sediments. A long table illustrates the association. This fact suggests the hypothesis that the absorption of carbonate disturbs the chemical equilibrium of subalkaline magma in such manner that alkaline fractions are produced by differentiation. Most of the alkaline species are ascribed to the interaction of basaltic magma and limestone (or dolomite), but more acid magma is also sensitive to the solution of carbonate. The hypothesis explains the concentration of alkalies; the desilication shown by the crystallization of nephelite, leucite, corundum, etc.; the extreme variability of alkaline bodies in mineralogical and chemical composition; the occurrence of such lime-bearing minerals as melilite, scapolite, wollastonite, melanite, etc., and CO_2-bearing minerals as cancrinite and primary calcite. Suggestions are offered as to some of the chief physico-chemical reactions involved.—(AUTHOR'S ABSTRACT.)

GEORGE, R. D., State Geologist, and Others. *Colorado Geological Survey, First Report*, 1908.

The report contains the following papers: "The Main Tungsten Area of Boulder County," by R. D. George, with notes on the intrusive rocks by R. D. Crawford, pp. 7–104; "The Montezuma Mining District of Summit County," by H. B. Patton, pp. 105–44; "The Foothills Formations of Northern Colorado," by Junius Henderson, pp. 145–88; "The Hahns Peak Region, Routt County" (an outline survey), by R. D. George and R. D. Crawford, pp. 188–229.

"The Tungsten Area of Boulder County." The ores are found in veins in a region of biotite granite and granitic gneiss, the latter grading into quartz-mica schist and mica schist. These older rocks are cut by dikes and irregular bodies of granite and both coarse and fine pegmatite. In the northern and western parts of the district are many dikes which are described by R. D. Crawford as dacite, latite, latite porphyry, andesites of various sorts, diabase, basalt, basalt porphyry, lamprophyre, pyroxenite, and limburgite.

"The Montezuma Mining District." The schistose rocks are described as the Idaho Springs Formation and the Hornblende Gneiss Series. In the former, quartz, biotite, and sillimanite are the most abundant minerals, the most characteristic rock being called a mica-sillimanite schist. The igneous rocks include three types of granite, porphyries of various sorts, aplites, pegmatites, and a diabase. The ore deposits occur in several of these rocks but their genetic relationships are not determined.

"The Hahns Peak Region." The igneous rocks include effusive rocks and dikes ranging from rhyolite to olivine basalt, with plutonic diorite and gabbro. Quartz basalt is found in several dikes in the western part of the district. Extreme contact metamorphism is developed at the contact of the porphyries with the sedimentary rocks. E. R. LLOYD

HALLE, G. "Neuer Hand-Demonstrationsapparat für alle Erscheinungen der Doppelbrechung im Kalkspat," *Zeit. Kryst.*, XLVII (1910), 376–77.

Describes an apparatus for the demonstration of double refraction; the calcite prisms are smaller than those generally used, the desired effect being obtained by the use of a magnifying glass. For class work, the instrument is provided with a dicroscope and an aperture for mica wedge.

W. T. SCHALLER

LEISS, C. "Mikroskop mit gemeinsamer Nicoldrehung in vereinfachter Form," *Zeit. Kryst.*, XLVII (1910), 377–78. Fig. 1.

A simple arrangement, suggested by Dr. F. E. Wright, by which both nicols can be simultaneously rotated by means of a rigid vertical bar.

W. T. SCHALLER

MACKIE, WILLIAM. "The Distribution and Signification of Deviations from the Normal Order of Crystallization, also the Distribution and Significance of Micropegmatite in Granites, as Illustrated by the Granites of the North of Scotland." *Trans. Edinburgh Geol. Soc.*, IX (1909), 247–317. Diagrams 6, photomicrographs 8.

The author found in previous microscopic investigations of granites from the north of Scotland, that deviations from the normal order of crystallization existed in almost every rock-slide examined, and the occurrence of patches of micropegmatite was far more frequent than indicated in previous descriptions of such rocks. The present research was undertaken

to obtain data as to the order of crystallization, the occurrence and distribution of micropegmatite, and, if possible, to arrive at some definite conclusions as to the origin and causation of the observed phenomena.

The author recognizes three kinds of micropegmatite: (*a*) intergrowths developed in the regular course of crystallization, (*b*) centric or radial forms developed in connection with and radiating from the edges of the feldspars, and originating in the reactions between the various minerals in contact with it, and (*c*) the form of micropegmatite presented by the matrix in which the other minerals are imbedded. From 182 slides examined, representing 90 different rocks, it was found that type *a* occurred in 23.3 per cent, *b* in 68.8 per cent, *c* in 13.3 per cent, and absence of any form of micropegmatite in 17.7 per cent.

In examining the sequence of crystallization the author found that any two minerals, whose periods of crystallization overlap, even where one of them is crystallizing at an abnormal period, may appear in micropegmatitic intergrowth; and the relative frequency of occurrence of any single pair in such combination is in proportional relation to the general coincidence of the crystallization periods of the particular minerals entering into the combination. Besides the usual intergrowths of quartz and orthoclase, the author found intergrowths of quartz and hornblende, orthoclase and hornblende, plagioclase and hornblende, sphene and hornblende, magnetite and hornblende, biotite and hornblende, quartz and biotite, orthoclase and biotite, plagioclase and biotite, quartz and plagioclase, orthoclase and plagioclase, quartz and microcline, microcline and plagioclase, quartz and sphene, plagioclase and sphene, orthoclase and sphene, biotite and sphene, quartz and epidote, and epidote and orthoclase.

All the phenomena are most readily explained on the theory of the origin of granite by crystallization from solution. The process is not always progressive, but at certain stages reversions come in and partake of the nature of re-solution of parts that had already become solid.

In conclusion the author gives in detail the various stages that appear to be indicated in the crystallization of a granite, and considering that the normal biotite granites have been derived by differentiation from a hornblendic magma, he gives the following stages for all granites: (1) At a temperature probably somewhat above 1,100° C., hornblende began to crystallize. (2) In supersilicated hornblendic magmas, quartz, orthoclase, and an acid plagioclase, or any combination of them, may appear along with the last of the hornblende, the appearance of these minerals in this connection being apparently due to their solubility in the originally liquid hornblende. (3) Partial resorption of these minerals, and in particular of

orthoclase, may occur, apparently in consequence of the heat liberated by the crystallization of the hornblende. (4) Crystallization of sphene, sometimes simultaneous with, sometimes previous to, the hornblende, and in some cases even somewhat later, and at times around previously separated and partially resorbed quartz, orthoclase, and plagioclase nuclei. (5) Crystallization of biotite, with occasional resorption of hornblende—probably in consequence of, or at least aided by, the heat liberated by the crystallization of the biotite, with the subsequent separation of more quartz; but independently of this, quartz, orthoclase, and plagioclase may also appear in connection with biotite for the same reason that they appear in connection with the hornblende, viz., from solution in the originally liquid biotite. (6) Crystallization of plagioclase with occasional resorption of some of the biotite, with subsequent liberation of magnetite. (7) Crystallization in supersilicated magmas of part of the quartz, often as micropegmatite of the *a* type along with plagioclase, and later, in like manner, with orthoclase also. (8) Crystallization of orthoclase, with solution, in part, of the plagioclases, apparently from heat of crystallization of the orthoclase with subsequent development of micropegmatite of *b* type in the areas of solution. (9) Solution also, in part, of the earlier orthoclases during the crystallization of the later orthoclases, also with development of micropegmatite of *b* type in the areas attacked. (10) Crystallization of remaining portion of quartz with little or no action on the previously crystallized minerals. (11) Crystallization of microcline if present, with partial solution of plagioclases and orthoclases—the latter in limited degree—with subsequent development of micropegmatite of *b* type in the areas of solution. (12) Crystallization of remaining liquid magma, if any, with varying conditions, occasionally as micropegmatite of the *c* type, occasionally as microgranite.

ALBERT JOHANNSEN

NIKITIN, W. "Drehbarer Compensator für Mikroskop," *Zeit. Kryst.*, XLVII (1910), 378–79. Fig. 1.

Describes a sensitive instrument for measuring weak double refraction.

W. T. SCHALLER

NIKITIN, W. "Halbsphäroid zur graphischen Lösung bei Anwendung der Universalmethode," *Zeit. Kryst.*, XLVII (1910), 379–81. Fig. 1.

An apparatus to replace the stereographic net. Used in connection with a Fedorow Universaltisch, the optical constants may be directly drawn, with a pencil, upon the unglazed porcelain surface of the half sphere.

W. T. SCHALLER

NOBLE, L. F. "Contributions to the Geology of the Grand Canyon, Arizona, The Geology of the Shinumo Area, (continued), Part II," *Am. Jour. of Sci.*, iv ser., XXIX (1910), pp. 497–528. Pl. 1.

The writer gives a detailed description of the stratigraphy and lithology of the Unkar (Algonkian) rocks of the area. The sedimentary rocks consist mostly of alternating shales and quartzitic sandstones with some slate and considerable thicknesses of limestone.

The diabase intrusions described are of special interest. A sill of from 650 to 950 feet in thickness is intruded above one of the limestone members. Below this intrusive occurred large amounts of serpentine in bands and nodules. These show no trace of an alteration structure which might indicate a derivation from pyroxene, hornblende, or olivine. This fact and the fact that serpentine and asbestos are not developed within the diabase itself lead the author to believe that they are the result of contact metamorphism, conditioned by the invasion of the limestone by the diabase. The diabase itself consists primarily of plagioclase feldspar (near labradorite) and olivine in about equal amounts, with a subordinate quantity of augite and brown biotite. Ophitic intergrowths of augite and plagioclase occur throughout, and pegmatite dikes cut the mass.

At one point the rock at its upper contact is a pink hornblende syenite which appears to grade downward into the normal diabase. Transition specimens were not collected and the author's suggestion that the syenite is due to differentiation in place is only tentative.

A map showing the distribution of Algonkian rocks in the Grand Canyon region is appended.

ALBERT D. BROKAW

PARSONS, A. L. "Ein neues Sklerometer," *Zeit. Kryst.*, XLVII, (1910), 363–70. Figs. 2.

Describes a new instrument for measuring hardness, giving the construction and adjustments of the instrument and a few comparative results.

W. T. SCHALLER

RANSOME, F. L. "Notes on Some Mining Districts in Humboldt County, Nevada," *Bull. U.S. Geol. Survey No. 414*. Pp. 71. 1909.

These notes are based upon reconnaissance work. With the exception of a small portion, the field had been previously geologically mapped by the Fortieth Parallel Survey. In general, the granites described as Archean by that survey are intrusives in Mesozoic rocks; many of their Triassic

quartzites are rhyolites, and thorough study would probably change many of the names applied to the igneous rocks. Some are pre-Tertiary, but most of them are Tertiary in age. Among the effusives are andesites, rhyolites, basalts, tuffs, and breccias. The granular rocks occur less abundantly. Those mentioned are granodiorites, hornblende-gabbros, diorites, monzonites, micaceous granites, granite- and diorite-porphyries.

The paper concludes with a list of minerals found in the district.

CHARLES J. HARES

SPITZ, ALBRECHT. "Basische Eruptivgesteine aus den Kitzbüchler Alpen," *Tscher. Min. Petr. Mit.*, XXVIII (1910), 497–534.

In the so-called Silurian schists of the Kitzebüchlian Alps, occur two groups of basic eruptive rocks. One group consists of undoubtedly effusive sheets and tuffs, interbedded with the schists; the other consists of isolated outcrops whose mode of occurrence is indeterminable.

The rocks described are monzonite-diabase, ordinary and olivine diabase, diabase porphyrite, hornblende diabase (proterobase), hornblende picrite, proterobase amygdaloid, albite-chlorite schist, and epidote-chlorite schist. The rock of greatest interest is the one to which the writer gives the name of monzonite diabase. With this term he wishes to designate all rocks which carry potash feldspar in greater quantity than is normal in diabases, but does not say that the amounts of orthoclase and plagioclase must be equal. Brauns and Erdmannsdörfer have previously described rocks which contain greater amounts of potash and which are transitional to essexites and theralites. The monzonite diabases differ from essexite- and theralite-diabases in the greater amount of SiO_2 in the former, so that they are sometimes quartz-bearing and are then related to Kongadiabase.

The plagioclase in the monzonite diabase is almost pure albite, which the author says is only comprehendable by considering it due to alteration. The potash feldspar occurs in part in irregular patches in the plagioclase, in part as interspaced filling. Much of it is peculiar in having a small axial angle, $2V=48°$, and in being optically positive. The pyroxene is enstatite augite (Mg-diopside of Rosenbusch), and is sometimes intergrown with brown hornblende. Ilmenite is present and there is much apatite. The texture is divergent-strahlig-körnig (Lossen's term for ophitic). The iron minerals and apatite were the oldest, and quartz and micropegmatite the youngest minerals to form. Pyroxene and feldspar are essentially of the same age, for they mutually inclose each other.

A chemical analysis of a quartz-free monzonite diabase from Weissenbachtal near Ellmau gives: SiO_2 49.86, Al_2O_3 13.01, Fe_2O_3 13.78,

MgO 3.50, CaO 7.26, Na_2O 4.00, K_2O 1.66, H_2O 2.08, TiO_2 0.69, P_2O_5 0.38, CO_2 2.08=99.45. The rock is considerably altered and its computation is difficult. According to Osann's system it shows: $s=58.3$, $a=3.5$, $c=1.9$, $f=14.6$, $n=7.9$, $k=0.90$. It is related to the Kongadiabase of Hartenrod near Herborn, the diabase from Rocky Hill, New Jersey, the Hunnediabase from Campo Santo, the Hunnediabase from Halleberg, and the diabase from Richmond, Cape Colony.

(The rock is an alkali diabase or an orthoclase-albite diabase).

ALBERT JOHANNSEN

UHLEMANN, ALFRED. "Die Pikrite des sächsischen Vogtlandes," *Tscher. Min. Petr. Mit.*, XXVIII (1909), 415–72. Maps 1, figs. 17, photomicrographs 8.

The picrites here described occur in surface flows, dikes, and intrusive sheets, and are generally associated with granular diabases. The period of eruption began at the end of the Silurian and ended before the beginning of Middle Devonian.

The author particularly examined the relations between the picrites and the diabases, for, according to Rosenbusch, picrites are feldspar-free olivine diabases, and picrite porphyrites are feldspar-free melaphyres, and there are gradations from one to the other. The present study does not confirm this. An analysis was made of the normal diabase, another of the same rock near the contact, and a third of the picrite near the contact, and while there is an enrichment of magnesia in the contact diabase, this is explained by the assimilation of fragments of the picrite through which the diabase was erupted. The author believes that the cause of the association of diabase and picrite is not to be found in differentiation after eruption, but in intratelluric differentiation from a single magma.

In habit the picrites are coarse granular ($\frac{1}{2}$–2 cm.), more rarely medium-grained (2–4 mm.), pyroxene-olivine rocks, with less amounts of iron ores and apatite, and rarely basic plagioclase. Locally there is found primary biotite, rhombic pyroxene, or a globulitic and trichitic intersertal basis.

Two analyses of the picrites were made by the author and an older one from Gümbel is given for comparison. All of them are computed in Osann's system and the following formulae are found:

$$S_{44\cdot8},\quad a_0,\quad c_1,\quad f_{19},$$
$$S_{37}\ ,\quad a_0,\quad c_1,\quad f_{19},$$
$$S_{42\cdot1},\quad a_0,\quad c_1,\quad f_{19},$$

which shows a remarkable resemblance between the three specimens from widely separated areas.

Three types of picrite are distinguished according to texture: (1) hypidiomorphic-granular (all the analyzed specimens belong to this group); (2) holocrystalline-porphyritic rocks with hypidiomorphic-granular groundmasses; and (3) hypocrystalline-porphyritic rocks with intersertal groundmasses.

Since such different textures are included among the picrites, the author proposes for the third type, from its occurrence at Altschönfels, the name of "Schönfelsit." In composition, Schönfelsite is a porphyry with closely crowded phenocrysts (persemic) of olivine and augite in a megascopically aphanitic ground-mass. Microscopically this ground-mass is seen to consist of rare apatite, aggregates of titaniferous magnetite, granular augite, long prismatic crystals of bronzite, automorphic laths of bytownite-anorthite (sometimes anorthite), and a gray or brown devitrified basis. The occurrence of basis in picrite is noteworthy and points to the effusive nature of the occurrence. This basis fills the interstices between the divergent laths of feldspar and also occurs between the pyroxene grains as a distinct interstitial filling. It is completely made up of fine scaly particles of a chloritic aggregate in which there still remain well-preserved trichites and globulites.

There are numerous secondary minerals found in the picrites described. They are tremolite, uralite, antigorite, bastite, pseudophite, pennine, delessite, prochlorite, talc, dolomite, siderite, epidote, kaolin-like products, and magnetite.

Albert Johannsen

Tutton, A. E. H., *Crystalline Structure and Chemical Constitution.* London: Macmillan, 1910. Pp. viii+200, figs. 54. \$1.50 net.

The title of this book is perhaps a little misleading, as it is not a general treatise on the subject, but is rather, as is stated in the Preface, an effort to present in a concise manner the author's original contributions to the subject of the relation between the form, structure, and physical properties on the one hand, and the chemical composition of the substances on the other.

The first four chapters are devoted to a historical sketch by way of introduction. The Haüy-Mitscherlich controversy on isomorphism is reviewed in its relation to more views on the subject. In a discussion of the periodic classification of the elements in its relation to isomorphism, the author digresses for a moment to decry the growing usage of oxygen = 16 instead of hydrogen = 1 as a basis for atomic weights. His reasons seem to be sentimental rather than practical, as chemists in general are agreed as to the advantages of the former.

After an instructive introduction to the study of isomorphous series the author proceeds to describe improved apparatus that he found it necessary to devise before his measurements could be made with the required precision. Perhaps the most important of these is a cutting and grinding goniometer. By means of this instrument it is possible to cut truly plane surfaces, oriented with almost mathematical accuracy. Either parallel-faced sections or 60° prisms may be cut by changing appliances. The instrument and its operation are described in detail.

A spectroscopic monochromatic illuminator for use in the study of the optical properties is substituted for the usual Na-light, K-light, Li-light, etc., with very satisfactory results. It involves little that is new in principle, though considerable ingenuity is expressed in the mechanical details. In a dilatometer for measuring the expansion of variously oriented sections, and in an elasmometer for the study of the elastic properties the well-known interferometer method of measuring minute distances is employed with gratifying results.

After describing his apparatus the author takes up a discussion of his own studies of two isomorphous series, namely the orthorhombic $R_2\genfrac{}{}{0pt}{}{S}{Se}O_4$ series and the monoclinic $R_2M\left(\genfrac{}{}{0pt}{}{S}{Se}O_4\right)_2 \cdot 6H_2O$ series, in which R may be potassium, caesium, rubidium, ammonium, or thallium, and M may be any one of a number of bivalent metals, though discussion is limited chiefly to the zinc and magnesium compounds.

The members of each series were submitted to a comparative study in regard to their external form and various vector properties, as refractive index, birefringence, and expansion coefficients. A number of these properties were shown to vary progressively when a heavier metal is substituted for a lighter, but apparently these variations do not bear any simple mathematical relation to the atomic weights. A marked divergence of the ammonium and thallium salts from the rest of the series is explained on the basis of their chemical differences from the true alkali metals. Similar progression, with a divergence in the cases of thallium and ammonium, is noted in the solubilities, but unfortunately the absolute solubility, in grams per liter, is discussed instead of the more significant molar solubility.

In the orthorhombic series the axes of the ellipsoid of thermal expansion were found to be coincident with the axes of the optic ellipsoid and in the monoclinic series one of the axes of the thermal ellipsoid coincides with the axis of symmetry, as might have been anticipated. It is unfortunate

that the elastic properties of oriented sections are not discussed, as they would doubtless form an interesting addition to the subject.

The author's studies of crossed axial dispersion are presented in an extremely interesting chapter. A plate shows the crossing of the optic axes due to change in wave-length, the series of figures for two temperatures being given. Although it is not pointed out by the author, these figures show that for these salts the change in position of the optic axes for monochromatic light, with increasing temperature, is in the same direction as the change in position due to decrease in wave-length at constant temperature.

The author's conclusions are concisely summarized in the next to the last chapter. The new term eutropic series is defined as a series "in which the small angular differences and also the physical properties of the crystals obey the law of progression according to the atomic weight of the interchangeable elements which give rise to the series and belong to the same family group of the periodic classification." Thus the thallium and ammonium salts belong to the above isomorphous series, but are excluded from the eutropic series to which the potassium, caesium, and rubidium salts belong.

Because of the close similarity between the ammonium and rubidium salts the author concludes that there is unoccupied space within the latticework of the crystal to allow for the eight additional atoms when the ammonium radical is substituted for rubidium. This may not be considered as proven, as it rests on the tacit assumption that the dimensions of the atoms, or their spheres of influence are the same, an assumption which seems hardly warranted, especially in view of Pope and Barlow's interesting explanations of the same phenomenon.

In the concluding chapter a comparison is drawn of the present status of crystallography with that of twenty years ago when the author began his work as a pioneer in the field of the more refined measurements of crystallographic characters. He points out that the measurements recorded are now on a plane of accuracy with atomic-weight determinations, whereas formerly gross errors entered into a large part of the work. Bare mention is made of the work of Pope and Barlow and their valence theory.

The book is well worth the attention of everyone interested in crystallography whether from the chemical or physical side, and leads one to look forward to the author's more general treatise which is to appear shortly.

ALBERT D. BROKAW

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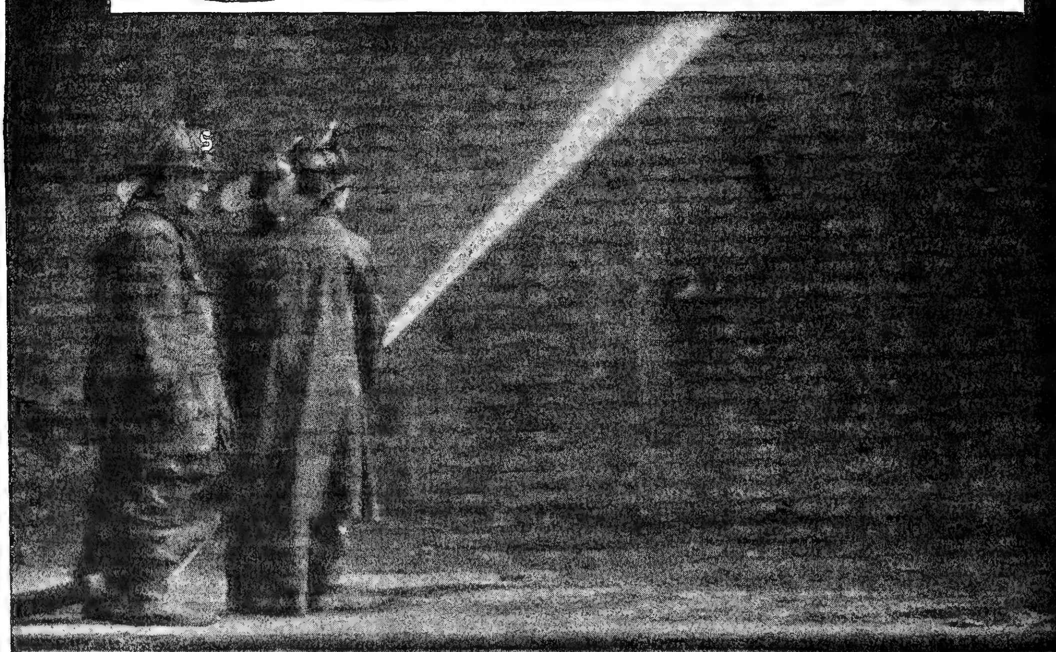

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NEW PERMIAN REPTILES: RHACHITOMOUS VERTEBRAE

S. W. WILLISTON
The University of Chicago

On the last day of field work by the University of Chicago Expedition to the Permian of Texas in the autumn of 1909, Mr. Lawrence Baker of the expedition discovered on Craddock's Ranch, about six miles from the town of Seymour, a remarkable deposit of fossil bones. All that could be done at the time was to collect a quantity of the loose bones from the surface. Work was begun upon the deposit by Mr. Paul Miller the present season, and, although the results obtained were not what had been hoped for and confidently expected, perhaps two hundred or more specimens were obtained. The bones were found almost invariably isolated, but in the most perfect preservation, for the most part entirely free from matrix; others were more or less covered by, or cemented together in, nodular concretions. The clay beds in which they were found, because of their usual barrenness, had never been thoroughly examined by previous collectors, and the bone deposit, though but a few hundred feet away from a well-traveled road, had been overlooked.

An incomplete examination of the material obtained shows a great variety of genera, not the less interesting because of their association. It includes various shark spines; a small quantity of *Diplocaulus* remains; at least three other forms of unidentified

amphibians represented by limb bones and parts of skulls; and certain large intercentra which agree well with those of *Trimerorhachis*. At least one of these amphibians has a wide dermal armor of a new kind, probably belonging with one or the other of the humeri from this deposit figured by me in my recent paper on *Cacops*.[1] Other limb bones and such parts of the carapace as have been recovered I will figure as soon as opportunity permits.

Among the reptile remains there are representatives of at least seven genera, including three distinct species of *Dimetrodon*, one of them the largest vertebrate hitherto recorded from the Permian of Texas; numerous vertebrae and teeth of *Diadectes;* limb bones which agree well with Case's figures of *Clepsydrops natalis*, and with limb bones in the collection obtained elsewhere; femora and humeri, as well as other limb bones of at least two distinct genera which I cannot yet identify, some of which are, with scarcely a doubt, new; vertebrae, parts of a humerus and femur which I refer to *Desmospondylus;* and the genus *Araeoscelis* herein described. Rather interesting is the fact that, so far, no certain evidence is forthcoming of the Pariotichidae, the curious acrodont *Pantylus*, Poliosauridae, Eryopidae, or Cricotidae. A few vertebrae having short spines with a pair of lateral tubercles suggest the probability of *Naosaurus*, and it is possible that some of the girdles and limb bones may be of this genus. Altogether I recognize in the deposit evidences of fourteen or fifteen genera and seventeen species.

Among the material recovered from this deposit is a temnospondylous coracoscapula, in which the three elements are separate. The suture between the coracoid and scapula is quite as in the pelycosaurian girdle, passing directly forward through the preglenoid articular facet and above the supracoracoid foramen. The metacoracoid is small, a mere vestige in fact. The evidence furnished, not only by the temnospondyls but by the almost identical structure of the coracoscapula of the contemporary reptiles, is, it seems to me, conclusive that there is no such bone as the procoracoid, that the coracoid of all modern reptiles is homologous with the anterior element, the so-called procoracoid, and not with the posterior one, which has disappeared, or remains as the merest

[1] *Bull. Geol. Soc. Amer.*, XXI (1910), 249, Pl. XV, Figs. 4, 5.

fused vestige. For this reason I abandon the term procoracoid and adopt the terms metacoracoid and coracoid, or epicoracoid if one desires a distinctive name for the anterior element, after Howes and Lydekker, the former of whom reached the same conclusion from the study of the mammals.

Araeoscelidae, family new.

Araeoscelis gracilis, genus and species new.

This species is represented by numerous remains found associated in a space of a few square feet, including various limb bones and vertebrae found free in the clay, and three or four more or less complete skeletons imbedded in clay nodules—in a more or less disturbed condition. There are parts or wholes of four or five skulls among them, but unfortunately their delicacy is such that they are more or less distorted and only by a careful preparation with needle and lens can one hope to determine their characters. This much however may be said: The teeth are placed closely together and are of uniform size, obtusely pointed as seen from the side, with their bases rather wider than long; there is but a single row. There is a row of slender conical teeth on the palate. The orbits are large, and almost certainly there is a single large temporal vacuity. The skull is lizard-like in shape, in the smallest about 30 millimeters in length; in the largest about 50.

The vertebrae, of which there are numerous free examples in the collection, in addition to several more or less complete series, in the nodules, are remarkable for their slenderness and delicacy. The dorsal vertebrae (Figs. 13, 17) are elongate, narrowly keeled below, with a rudimentary spine in front; there is a short diapophysis just back of the front zygapophyses; and intercentra are present.

The ribs, of which there are numerous free representatives, are rather stout and single headed—a unique character if it is representative of the whole dorsal series. The caudal vertebrae (Plate I, Figs. 11, 12) are remarkable for their great elongation and slenderness, having a slender carina on the under side, and a small parapophysial facet on each side in front, for the attachment of ribs, another remarkable character. The pectoral and pelvic girdles are present in at least two specimens, but are scarcely visible in

the hard matrix, save that the clavicles and interclavicle are seen to be very slender.

It is in the limb bones that the chief distinctive characters of the genus are found, characters hitherto unknown among American Permian vertebrates, characters which indicate a quick-running terrestrial, or, more probably, climbing reptile. The humerus (Plate I, Figs. 4, 5) is very slender and delicate, with slightly expanded extremities and a somewhat curved shaft. The articular head is elongate oval in shape, imperfectly separated from the lateral process, which is situated much closer to the head than in any other Permian reptile known to me. The bicipital fossa is rather deep, and there is no distinct median process. The distal extremity is very thin and flat, and only moderately expanded on the ulnar side. The entepicondylar foramen is small, and is situated some distance above the lower end. On the radial side there is a small ectepicondylar foramen situated close to the distal margin, formed by a bridge over the end of the ectepicondylar groove; it is very like the foramen of *Iguana*. The capitellum for the radius is perfectly formed, as is also the trochlear surface for the ulna; both of them are very small for the slender epipodial bones. There is no more characteristic bone in the early reptiles than the humerus. "Ein geübtes Auge und ein durch Nachdenken gescharfter Blick findet in dem Humerus der Reptilien zahlreiche Momente, welche von mehr oder minder systematischer Bedeutung sind, welche aber, was noch wichtiger ist, zugleich ein Stück Genealogie ablesen lassen."[1] Among Permian reptiles I know of none other in which the length exceeds the greatest width more than two and a half times; in the present species the length is three and three-fourths times the greatest width, a difference not often exceeded among reptiles. And, even in those reptiles with a higher index, I know of none in which the shaft is proportionally more slender. This extreme slenderness, together with the smoothness of the bones, the absence of muscular rugosities, and the perfectly formed articular surfaces, points, I think, toward climbing habits, or at least toward purely terrestrial habits. For comparison I have given in the plate (Figs. 1, 2) the most slender humerus of the American

[1] Fürbringer, *Jenaischer Zeitschr. für Naturwissensch.*, XXXIV (1900), 555.

Permian that I knew hitherto, and I know no less than twenty different forms of Permian humeri. It is that of one of the smallest of known Permian reptiles, *Pleuristion* Case, belonging in the Pariotichidae. As will be seen, however, the expansion of the extremities is great, though the shaft is slender. In the same plate (Fig. 3) I give a figure of the humerus of *Sphenodon punctatus* for comparison. It will be observed how clumsy the bone is in comparison with that of *Araeoscelis*. For comparison's sake I figure the humeri of *Pleuristion* and *Sphenodon* twice natural size. The concurrence of an entepicondylar foramen and an ectepicondylar groove is found in the pelycosaurs, but the groove is never converted into a foramen. That the presence of a foramen in the present genus is of great phylogenetic significance I do not believe.

The same slenderness is characteristic of the femur and leg bones. In Plate I, Figs. 7 and 8, I give, enlarged one-half for the sake of comparison, illustrations of a femur of one of the numerous young specimens, specimens lacking the articular ossifications and muscular markings. That it belongs with the same species as does the larger bone shown natural size in Figs. 9 and 10 there can be no doubt, notwithstanding the apparent differences, since about a dozen femora of various sizes are present in the collection, as also many humeri of various degrees of ossification and size. In the side view will be seen the remarkable sigmoid curvature so characteristic of the bone. The adult bone shows sharply defined the articular surfaces for epipodial bones, and, proximally, the well-developed, rounded head and trochanter. The shaft is proportionally somewhat stouter than is that of the juvenile bone, and the extremities are more sharply expanded. The tibia and fibula are extremely slender, very nearly or quite the full length of the femora; the tibia has a well-developed and protuberant cnemial process, better developed than I have observed in any other Permian vertebrate. The metapodials are likewise very slender, those of the hind feet apparently more so than those of the front feet, as are also their phalanges. I hope to be able in a later communication to give the complete or nearly complete structure of the hind extremities at least. The claws are slender and

sharp, the phalanges well formed. All the bones of the skeleton are very hollow.

Upon the whole the present animal must be a remarkably long-legged and long-tailed reptile, probably eighteen inches or more in length.

There are several small reptiles from the American Permian of which we yet have no published knowledge of the extremities, such as *Isodectes*, *Helodectes*, and *Pariotichus* sens. str., the most of which are at once eliminated from comparison with the present genus by reason of their roofed-over skulls. *Tomicosaurus* Case, described from a fragment of a mandible and several arches of vertebra differs in being a larger animal, and in the character of the teeth, as described by Case. The front teeth neither in the upper nor lower jaws are elongated or incisiform. Nothing is shown in the figures of the diapophyses. The two small vertebrae upon which the genus and species *Embolophorus fritillus* Cope were founded differ materially from those of the present genus. As to its ordinal position, nothing definite can be said of *Araeoscelis* till the skulls have been cleaned and studied, and possibly not even then, save of the presence of a temporal vacuity. To locate such a genus in the same group with *Dimetrodon* or *Naosaurus* seems a bit absurd.

Casea broilii, genus and species new.

The material upon which the present genus and species are based comprises, probably, several complete skeletons found associated with skeletons of *Varanosaurus* and *Cacops*.[1] The complete working out of the material may require a year or more. The characters are, hence, drawn from those parts of one skeleton now prepared, comprising the larger part of a tail, the sacrum, two lumbar vertebrae, pelvis, and the complete hind legs. I take pleasure in naming the genus and species after Doctors Case and Broili, who have extended our knowledge of the American Permian fauna so materially.

The chief character wherein the present genus differs from all hitherto known Permian reptiles of America is found in the ilium,

[1] *Bull. Geol. Soc. Amer.*, XXI (1910), 249–85, Pls. VI–XVI.

which has a broad anterior projection, and only a slight posterior one (Fig. 1, A) suggesting affinities with the African Therapsida.

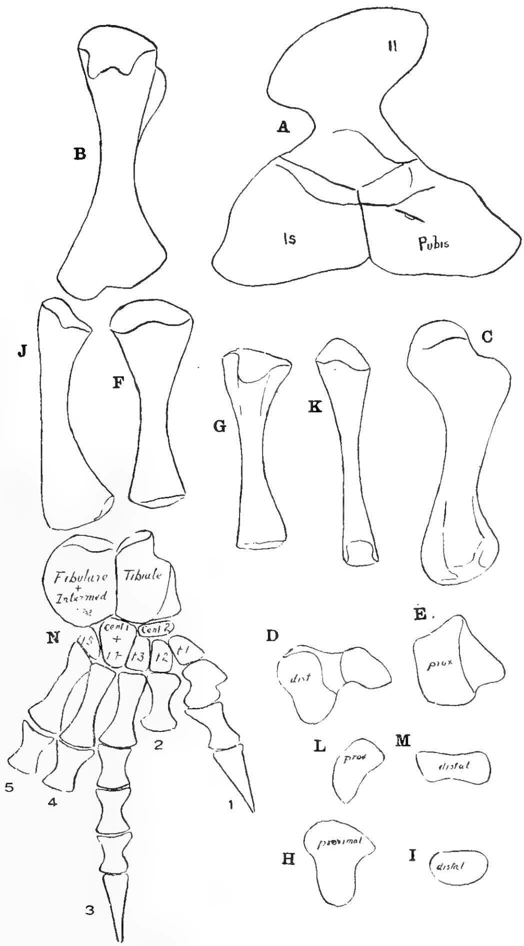


FIG. 1.—*Casea broilii* Will. A, right innominate, from without; B, right femur, dorsal; C, right femur, inner side; D, the same, distal end; E, the same, proximal end; F, right tibia, ventral; G, the same, dorsal; H, the same, proximal; I, the same, distal; J, right fibula, dorsal; K, the same, inner; L, the same, proximal; M, the same, distal; N, right foot, dorsal. All figures one-half natural size.

The pubes and ischia also differ markedly from both the clepsydropid and poliosaurid types in the absence of the platelike

projection anteriorly, agreeing rather better with the pariotichid type. The symphysis is continuous or nearly so throughout, without a median puboischiadic interval. The sacrum has three pairs of large sacral ribs, agreeing in this respect with the Clepsydropidae, and very different from the Poliosauridae, which have but two pairs. The spines of the vertebrae of the basal caudal, sacral, and lumbar regions at least are low cylindrical, with a nodular extremity, quite unlike the elongated forms of the Clepsydropidae and the moderately elongated and flattened spines of the Poliosauridae. Evidently the short co-ossified ribs of the lumbar regions are united to both arch and sacrum, and the ribs more anteriorly have double heads. None of the spines are elongated, as is indicated by numerous isolated vertebrae found in the wash. The femur (Fig. 1, B, C, D, E), tibia (Fig. 1, F, G, H, I), and fibula (Fig. 1, J, K, L, M) are sufficiently well shown in the figures. They are all much heavier and shorter than the corresponding bones of *Varanosaurus*. Of the feet (Fig. 1, N) I figure only those bones which were found in natural articulation; the remainder were detached in the feet studied. The phalangeal formula, as in *Varanosaurus* and *Dimetrodon*, is 2, 3, 4, 5, 4. The foot differs materially from that of *Varanosaurus* and its allies in the large size of the fifth digit. The second centrale is well ossified, whereas in *Varanosaurus* it was small in both front and hind feet and remained cartilaginous throughout life. It is very evident also that the foot was placed at a greater angle with the leg in walking. That the animal was of the crawling, lizard-like habit and form is undoubted. The present genus in all probability belongs to the order Pelycosauria as at present bounded. Nevertheless the marked differences in the pelvis may indicate corresponding differences in the skull. Furthermore I protest against the union of the Poliosauridae, or *Varanosaurus* at least, in the same group with *Dimetrodon* or *Naosaurus*. The structure of the skull, with no lower temporal arcade, aside from other characters of the skeleton sufficiently justifies a subordinal position.

Trispondylus texensis, genus and species new.

A new genus and species of reptile is represented in the Chicago collection by a considerable part of a skeleton collected by Mr.

Paul Miller on Craddock's Ranch intimately associated with the remains of *Trematops* described by myself. The parts recovered consist of a nearly complete humerus, radius, ulna, numerous carpal and digital bones, a pelvis lacking part of the ischia and pubis, and a more or less connected series of nineteen vertebrae. The

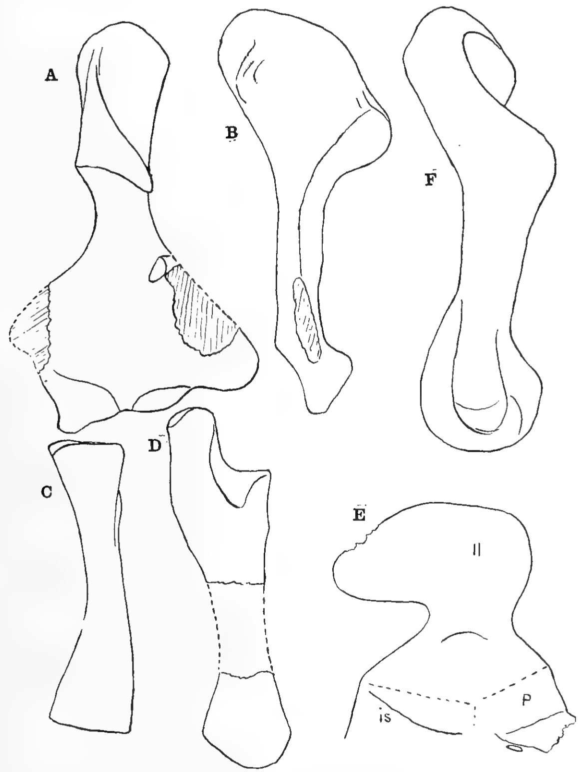


FIG. 2.—*Trispondylus texensis* Will. A, right humerus, ventral; B, the same, outer; C, right radius, dorsal; D, right ulna, dorsal; E, right ilium, outer; F, left femur, inner side. All figures one-half natural size.

vertebrae are in five series, three dorsal of three each, eight in another comprising two lumbar, three sacral, and three caudal, and two additional connected caudals. None of the spines of the vertebrae are preserved complete, but they are all evidently short. The centra are of nearly uniform length, a little shortened in the lumbar region, obtusely keeled below, or rather with the sides "pinched in." The ribs are double headed, the diapophyses anteri-

orly unusually long. Three of the basal caudals have intercentra, the first chevron appearing between the third and fourth caudals. The three pairs of sacral ribs are turned broadly down at their extremities, the expansion of the first pair nearly equal to the combined extent of the second and third pairs. The ilium (Fig. 2, E) has the ordinary form, turned broadly backward, and is wholly without an anterior projection. The humerus (Fig. 2, A, B) is massive and broad, with the distal extremity greatly expanded; the radius and ulna (Fig. 2, C, D) are likewise stout bones. The front feet show the usual structure, so far as the preserved remains enable one to decide; the intermedium is large, the second centrale is ossified, and the pisiform articulates with the distal end of the ulna. The femur (Fig. 2, F) is likewise a stout bone, especially characterized by the low position of the trochanter.

The genus is removed from the Poliosauridae by the possession of three sacral vertebrae; from the Clepsydropidae by the possession of short dorsal spines, and the different structure of the propodials, as will be seen by comparison of the same parts of *Clepsydrops* and *Dimetrodon*.

THE DEVELOPMENT OF HOLOSPONDYLOUS VERTEBRAE

In a recent paper[1] I discussed the views at present held as to the morphological significance of the rhachitomous pleurocentra and hypocentra in the evolution of vertebrae of the higher forms. The majority of paleontologists believe that the rhachitomous type of vertebra is a primitive one, though there are some, of whom Jaekel is one,[2] who deny it. The extraordinary resemblances in nearly all parts of the skeleton between the more specialized temnospondyls and the more generalized reptiles are almost a demonstration of genetic affinity. That we have in any known Permian forms the actual connecting links between the Amphibia and Reptilia is more than doubtful; it is more than probable that annectant forms must be sought for in older rocks, probably those of the lower part of the Pennsylvanian or Upper Carboniferous.

[1] *Bull. Geol. Soc. Amer.*, XXI (1910), 265.

[2] *Deutsch. geolog. Gesellsch.*, LVI (1904), 118; *Zoologisch. Anzeiger*, XXXIV (1909), 200.

If then we assume that the holospondylous vertebra has been evolved from the rhachitomous, it is a matter of much interest to determine how the evolution has occurred. The view which has obtained general acceptance, among American paleontologists at least, is that of Cope, so vigorously defended by Baur,[1] namely, that the pleurocentra have progressively developed to form the centrum of the amniote vertebra, the hypocentrum degenerating into the vestige usually called the intercentrum; while, as proposed by Cope and tentatively accepted by Baur, in the modern amphibians it has been the hypocentrum which has developed into the centrum, the pleurocentra disappearing. The theory more generally accepted by European writers is that the pleurocentra and hypocentrum have fused to form the centrum of all the higher vertebrates, the small elements called the intercentra representing, according to Gadow and others, the hypocentra pleuralia, which have been rarely found in the tail of certain temnospondyls. Or, in the words of Broili:

> Bei den Rhachitomen das Hypozentrum den ventralen Halbring und das Paar der Pleurozentren den dorsalen Halbring des Wirbelkörpers repräsentirt; anderseits folgt daraus, dass weder das Hypozentrum noch die Pleurozentren allein dem eigentlichen Wirbelkörper der Amnioten homolog sind, sondern das beide zusammen Hypozentrum plus Pleurozentren desselben entsprechen.[2]

A study of the material in the University of Chicago collections has convinced me of the general correctness of Cope's contentions and the incorrectness of the opposing views.

It is well known that in the older reptiles the odontoid of the atlas is a larger bone than in modern reptiles or higher vertebrates, and also that there is in the oldest forms invariably a large intercalating intercentrum between the odontoid and the body of the axis below, a bone that is small or wanting in modern reptiles, as also the older Crocodilia. In *Dimetrodon*, as will be seen in the accompanying figure (Fig. 3), the odontoid functions as the real centrum of the atlas, reaching quite to the ventral side between the atlantal and axial hypocentra. It has a deep conical cavity

[1] "Everybody is convinced that the pleurocentra of the Rhachitomi represent the centra of the higher vertebrates; and that the intercentra are homologous to the intercentra of the Sphenodontidae," etc.—*Amer. Nat.* (1897), 975.

[2] *Monatschr. d. deutschen geologischen Gesellschaft,* LX (1908), 240.

in its posterior end, that in apposition with the body of the axis, a cavity which extends through the bone as the notochordal canal. Not only does this cavity extend through this bone but its orifice, in *Varanosaurus* at least, is in apposition with a similar cavity in the occipital condyle, conclusively proving the nature of the basioccipital. Between the odontoid and the axis, below, there is a large, massive intercentrum, even larger than the atlantal hypocentrum. This latter intercentrum gives support only in part to the neuropophyses of the atlas, which rest chiefly on the odontoid.

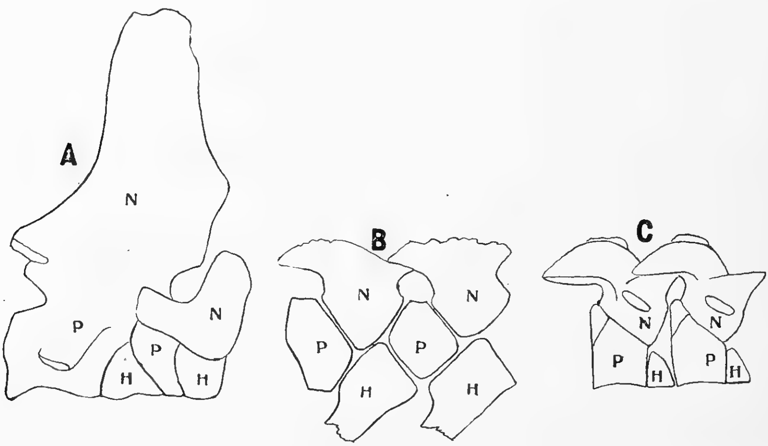


FIG. 3.—A, Atlas and axis of *Dimetrodon incisivus* Cope; B, caudal vertebrae of undetermined amphibian; C, vertebrae of *Desmospondylus anomalus* Will.; N, neurocentra; H, hypocentra; P, pleurocentra.

There can be no question that the odontoid is the combined pleurocentra of the atlantal vertebra, which has so far retained its primitive character that it gives chief support to the atlantal neuropophyses. Yet more conspicuously holospondylous in character is the atlas of *Poecilospondylus* Case, in which the dorsal arch appears to rest wholly upon the odontoid, and articulates in the usual way with the axis.[1] In *Eryops*, *Cacops*, and doubtless all other rhachitomous genera the vertebrae of the trunk have a perforating canal for the notochord formed by the junction of the pleurocentra in the middle above the hypocentrum, the three bones forming the canal; and it is chiefly because of this fact that Broili

[1] *Bulletin Amer. Mus. Nat. Hist.* (1910).

believes that the holospondylous centrum is formed by the fusion of the three bones. Under this theory, the intercentra, using the term as originally applied by Cope, must be morphologically different elements from the hypocentra. If such be really the case, it seems probable that all the known temnospondyl amphibians must be excluded from ancestral relationships with the reptiles, since none of them is known to possess additional elements in the trunk region. Aside from the improbability that the hypocentra pleuralia, known only in the tail of one or two temnospondyls I believe, have developed into so large a bone as is the axial intercentrum of *Dimetrodon*, the relations and structure of the axial and atlantal bones in the old reptiles furnish certain proof, it seems to me, that the odontoid is composed exclusively of the pleurocentra, though perforated by the notochordal canal; and Broili's argument falls to the ground.

Yet more conclusive evidence—it seems to me irrefutable—is furnished by two caudal vertebrae (Fig. 3, B) of an unidentified amphibian from the Texas Permian. The specimen was found by Mr. Paul Miller in the autumn of 1908 on the Little Wichita, unassociated with other bones. The size of the vertebrae rather precludes the probability of their belonging with *Eryops*, though possibly coming from near the extremity of the tail. However that may be, I doubt not that a similar structure will be found to be characteristic of *Eryops*, since by the aid of this specimen I determine a like structure in the tail of *Trematops*, as was indeed indicated by me in my paper descriptive of that genus.[1] Very probably the specimen pertains to a species of *Trimerorhachis*. The two vertebrae composing the specimen are closely associated, without distortion, and are uninjured, save for the loss of the greater part of the chevrons, and a part of the arch of the proximal vertebra. The two arches (NN), it will be seen in the figure, are wedged in between their adjacent pleurocentra (PP), resting in part upon the hypocentra (HH). The first pleurocentrum does not quite separate the two adjacent hypocentra below, which nearly touch at their extremities. The second pleurocentrum, however, is almost disklike, narrowed above and below, but separating by a

[1] *Journal of Geology*, XVII (1909), 647, Figs. 5, 16.

considerable interval both the arches and the hypocentra of the adjacent vertebrae. This pleurocentrum forms a complete ring, without traces of division, conically hollowed in its visible end and perforated by the notochordal canal. Its neurocentrum is much more closely and extensively combined with it than with the preceding pleurocentrum. In a few words, this vertebra is still typically rhachitomous, save that its fused pleurocentra form a disk separating the adjacent vertebrae, which is perforated like any holospondylous centrum by the notochord. The most imaginative eye will not see in this vertebra fused pleurocentra and hypocentrum with some other element taking the place of the hypocentrum, since the preceding apparently fused pleurocentra are not very different from the ordinary form. Doubtless the pleurocentra preceding these were progressively smaller, and those following progressively larger. To follow Jaekel's arguments to their extreme would necessitate the fusion of hypocentra and pleurocentra throughout, and the sudden introduction of an entirely different element in the chevrons to mimic the hypocentra, of all of which there is not the ghost of evidence!

The next stage in the evolution of the ordinary holospondylous vertebra may be seen in the reptile *Desmospondylus*, as recently described and figured by me,[1] an outline copy of two of the vertebrae of which I reproduce (Fig. 3, C). In his specimen it will be seen that the fused pleurocentra (PP) have increased in size, while the hypocentra (HH) have decreased, though still much larger relatively than in any other known reptile. The arch (N) rests in the same way upon the two adjacent pleurocentra, though functionally upon the posterior one, its own, and its lower extremity in front nearly touches the upper extremity of the hypocentrum.

From these three specimens it is not at all difficult, it seems to me, to understand clearly the way in which the different types of vertebrae have arisen. By the fusion of the neurocentrum with its respective hypocentrum, the embolomerous vertebra has arisen; by its sutural union with its respective pleurocentra the reptilian vertebra is produced; by the union of all three, I believe, the holospondylous amphibian vertebra has been evolved. It would

[1] *Bull. Geol. Soc. Amer.*, XXI (1910), 280.

require but little change in the size of the different parts to develop the second vertebra shown in B into one of those shown in C. In any event I think the specimens show conclusively that the hypocentra or intercentra are not the hypocentra pleuralia, as Gadow believes, nor the pleurocentra the fused pleurocentra and hypocentra, as Jaekel, Broili, and others believe.

Cope suggested that the pleurocentra were eliminated in the evolution of the holospondylous amphibian vertebra, but it seems more reasonable to me that there has been a fusion of all three elements in the Branchiosauria, Lepospondyli, and modern amphibians, from the fact that none of these amphibians are known to possess any vestiges as separate elements.

If this theory be true, that is the union of the hypocentra with some or all the other elements of the vertebrae in the amphibia, and their final loss, save as simple intercentra and chevrons in the amniota, it would offer of course the best class distinction between holospondylous amphibians and reptiles. In any event the structural differences seem too radical to unite forms with free chevrons articulating intercentrally with those having no free intercentra and the chevrons exogenous processes from the body of the vertebra. Nevertheless that is what is done in the order Microsauria. Baur some years ago reached the conclusion that *Hylonomus* and *Petrobates* were undoubted reptiles,[1] and his views were accepted by Fürbringer and others. A study of the specimen described by Cope and doubtfully referred by him to the species *Tuditanus punctulatus* Cope under the name *Isodectes* (*Eosauravus copei* Will., *Isodectes punctulatus* Moodie, nec Cope) convinces me that the genus is allied to *Hylonomus*, and consequently is a true microsaur, since *Hylonomus* Dawson is the type, with *Dendrerpeton* Owen, and *Hylerpeton* Owen, of the order Microsauria, as proposed by Dawson in 1863 (Airbreathers of the Coal Period). Whether *Hylonomus*, *Petrobates*, *Eosauravus*, and *Sauravus* Thevenin are true reptiles, even though having free chevrons, will not be positively determined until the structure of the skull has been made out. Whatever is the final disposition of them, they must be excluded from the Amphibia, and doubtless the ordinal name Microsauria will remain

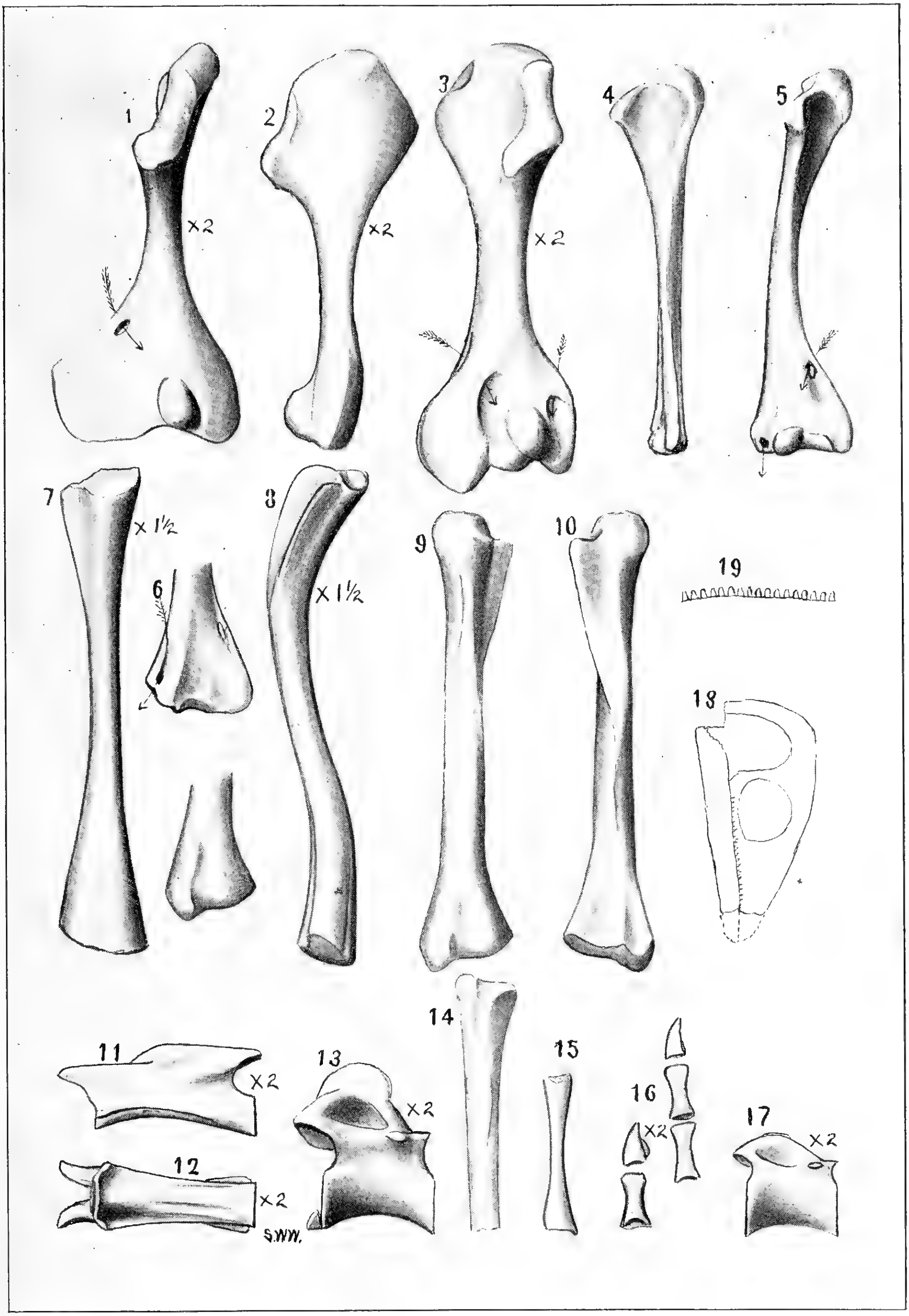
[1] *Anatomischer Anzeiger*, XIV.

valid for them. With the elimination of these genera, and perhaps others, from the Amphibia there remain a number of others hitherto classed under the Microsauria, of which *Urocordylus*, *Crossotelos*, and perhaps *Diplocaulus* are typical, that are genuine stegocephalian amphibians, which can no more be classed with the Reptilia than a salamander can. They have exogenous chevrons, and double-headed ribs attached to body and arch, true amphibian characters, the former utterly unknown among reptiles, save apparently in such rare cases as *Clidastes* among the mosasaurs, purely the result of a secondary anchylosis. There have been plenty of terms proposed to include them, such as Nectridea Miall, Lepospondyli Zittel, Diplocaulia Moodie, Holospondyli Jaekel. For myself I prefer the term Lepospondyli. Jaekel's class Microsauria is untenable.

Whatever may be the final disposition of *Lysorophus*, which I have referred to the order Urodela or Caudata, there can be hardly a question of its urodelan affinities. It has nothing to do with the Gymnophiona. The abundant material in the University collections demonstrates the presence of small limbs in numerous specimens. Amphiuma-like in form it had Amphiuma-like habits and limbs. I may also add that the supposed proatlas described both by myself and Case is merely the arch of the so-called atlas.

EXPLANATION OF PLATE

FIG. 1, *Pleuristion brachycoelus* Case, left humerus, ventral side; FIG. 2, the same, outer side; FIG. 3, *Sphenodon punctatus*, left humerus, ventral side; FIG. 4, *Araeoscelis* gracilis Will., right humerus, inner side; FIG. 5, the same, ventral side; FIG. 6, the same, distal end, dorsal side; FIG. 7, *A. gracilis*, left femur of young individual, dorsal side; FIG. 8, the same, inner side; FIG. 9, *A. gracilis*, adult femur, dorsal side; FIG. 10, the same, ventral side; FIG. 11, *A. gracilis*, caudal vertebra, side view; FIG. 12, the same, from below; FIG. 13, *A. gracilis*, dorsal vertebra, from side; FIG. 14, *A. gracilis*, upper part of tibia; FIG. 15, *A. gracilis*, metapodial; FIG. 16, *A. gracilis*, phalanges in position as found; FIG. 17, *A. gracilis*, dorsal vertebra; FIG. 18, *A. gracilis*, sketch of skull; FIG. 19, *A. gracilis*, mandibular teeth. All figures natural size, save where indicated.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THE PHYSIOGRAPHY OF THE BISHOP CONGLOMERATE, SOUTHWESTERN WYOMING[1]

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Cornell University, Ithaca, N.Y.

Introduction.—The purpose of this paper is the description of a series of peculiar, gravel-capped plateaus in the southwestern part of Wyoming, and an attempt to decipher, in so far as the evidence will permit, the physiographic history of the region both before and after the deposition of the gravels. It will be shown that a study of the physiography leads to some interesting and suggestive conclusions as to past changes in the geography of the region described, which on the whole agree remarkably well in broader features with certain conclusions which have been reached from other lines of approach.

Geologists are recently beginning to recognize more clearly than ever before the importance of climatic conditions in determining the nature of the geologic processes at any given time, and in determining the nature of the deposits formed as a result of these processes.[2] At the same time they are beginning to reason back from the character of a deposit to the causes which are responsible for its distinctive features; to the climatic and other conditions under which the deposit was made. It is one of the purposes of this paper to call particular attention to this line of study by attempting to show from physiographic evidences that there have been in comparatively recent geological times a series of marked climatic changes affecting the region under discussion.

[1] Published by permission of the Director of the U.S. Geological Survey. The writer is indebted to Dr. Alfred R. Schultz for information in regard to conditions on Little Mountain, for certain of the accompanying photographs, and for helpful discussions in field and office; also to Professor A. C. Gill for a reading and criticism of the manuscript.

[2] Joseph Barrell, "Climate and Terrestrial Deposits," *Jour. of Geol.*, XVI; Ellsworth Huntington, "The Glacial Period in Non-glaciated Regions," *Bull. Geol. Soc. Am.*, XVIII, 351–88; Chamberlin and Salisbury, *Text Book of Geology.* III, 305–7, 452–53.

The paper, aside from its descriptive part, is an inductive and deductive study carried out with the idea of reconstructing the past history of the region from the physiographic features still remaining.

There is in the southwestern part of Wyoming a belt of plateau country skirting along the northern base of the Uinta Mountains

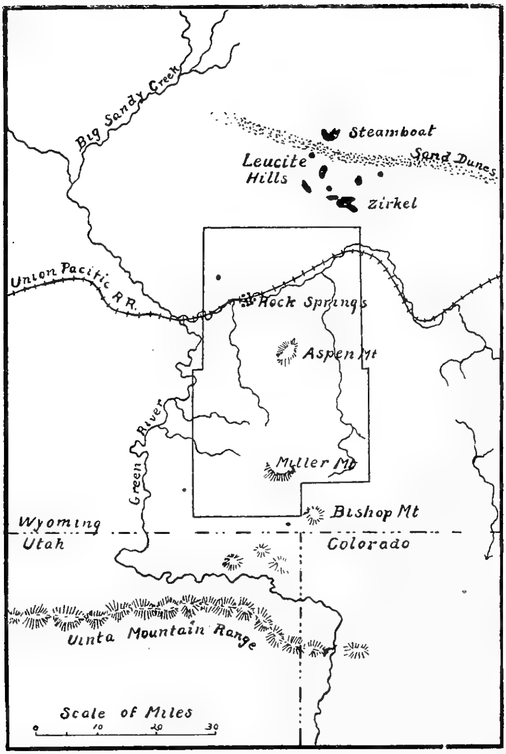

FIG. 1.—Sketch map of portions of Wyoming, Utah, and Colorado, showing the general location of the features described in this paper.

in an east-and-west direction parallel to the range. This has a general slope to the north away from the mountains. During the summer of 1908 a portion of the plateau lying north of the eastern end of the range and north and east of Green River was mapped in detail by a United States Geological Survey party. The conditions observed in that portion of the area form the basis of this paper. Fig. 1 is a sketch map of parts of southwestern

Wyoming, Utah, and Colorado which will indicate the general location of the region and its relation to the near-by important physiographic and geographic features. Fig. 2 is a more detailed map of a portion of the area outlined in Fig. 1 and shows all the various topographic, hydrographic, and cultural features referred to in the following discussion.

Referring now to the detailed map it will be noted that the entire area is drained by tributaries of Green River. Bitter Creek, one of the largest of these entering from the east, drains all but the extreme southern and western part. Red Creek takes the waters of the southern part directly south to Green River, and Sage Creek, flowing northwest, carries the drainage of the western part directly to the river.

The climate is semi-arid, with an average rainfall of from ten to fifteen inches per year. The topography is typically that of a semi-arid region of moderate relief; low areas, corresponding to belts of soft rock, are followed by steep scarps with dip slopes. Each zone of harder rocks is represented by a more or less pronounced scarp, depending on the resistance, thickness, and dip of the component layers. One of these scarps formed by a series of heavy-bedded sandstones is over 1,000 feet in height.

The plateau.—The most conspicuous feature of the topography within the area of the detailed map is a high, even-topped plateau lying at an elevation of from 1,000 to 1,500 feet above the bottoms of the major stream valleys. This is everywhere capped by a gravel-deposit partly consolidated at the base into a resistant conglomerate which, on account of its resistance to erosion, is responsible for the preservation of the plateau while the surrounding country was worn down. From its northern extremity at the northwestern base of Aspen Mountain the plateau extends southward for a distance of fourteen miles to Miller Mountain where it ends abruptly in a steep scarp facing southward to the basin of Red Creek. The plateau varies in width from less than a mile to eight or ten miles. The largest remnant extends southward from Aspen Mountain to Miller Mountain as indicated, but there is a long arm running northwest from Miller Mountain between the valleys of Sage and Little Bitter creeks for a distance

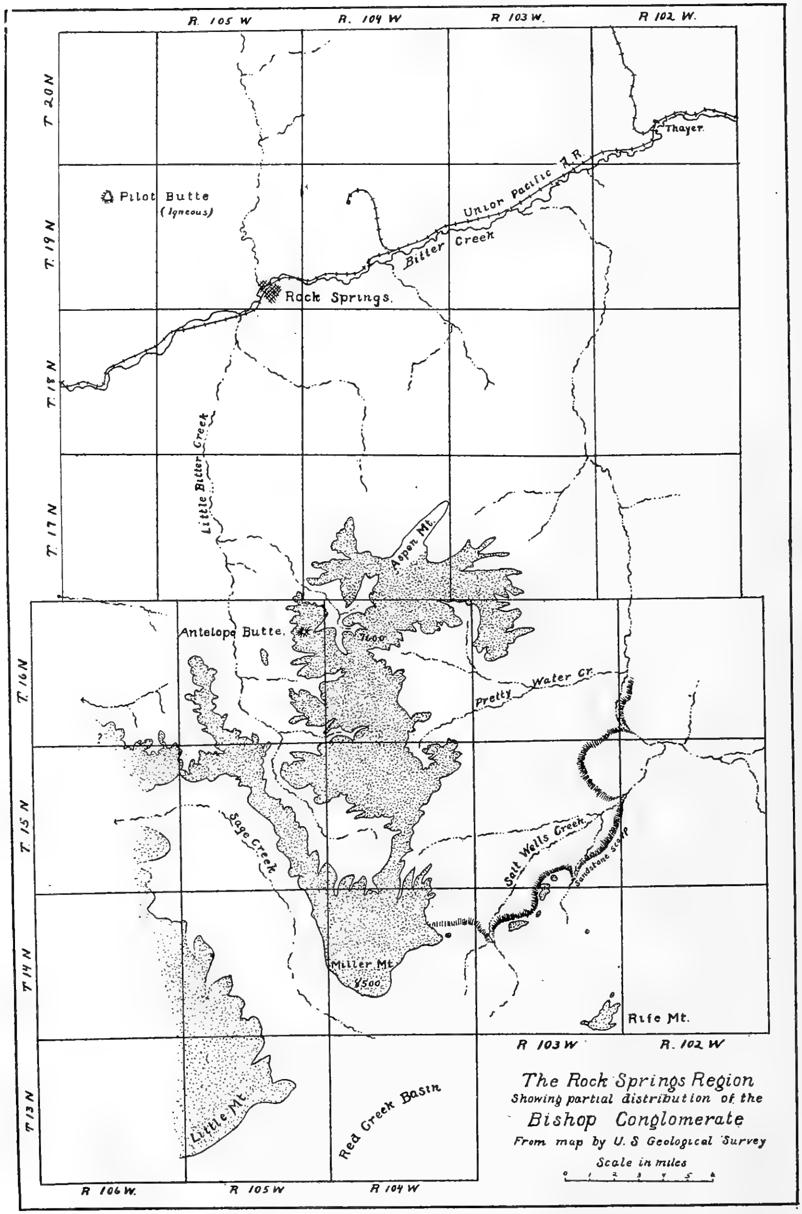

FIG. 2.—Map of the Rock Springs region

of fifteen miles or more, nearly to Green River. A similar plateau, known as Little Mountain (Quien Hornet Mountain of the Powell Survey), lies to the west and southwest of Miller Mountain, from which it is separated by the deep valley of Sage Creek. Rife Mountain, a flat-topped mesa about two miles long by one mile broad lying nine miles east of Miller Mountain, is a detached remnant of the same plateau lying at an accordant altitude and capped by similar gravels. Between this and Miller Mountain are five smaller isolated gravel-capped areas lying at accordant altitudes. Ten miles southeast of Miller Mountain is a good-sized remnant of the same gravel-capped plateau known as Bishop Mountain, or sometimes locally as Pine Mountain. It is from this plateau that the gravel-formation, the Bishop Conglomerate, receives its name.

Bishop Mountain is the type locality of Powell's "Bishop Mountain Conglomerate" as defined in his Uinta Mountain report. The shorter term, "Bishop Conglomerate,"[1] has however recently been adopted by the Board of Geologic Names, and is, therefore, used here in preference to Powell's name. The Bishop Conglomerate is the same as the "Wyoming Conglomerate" of this same region as described by King in his "Survey of the 40th Parallel."

The surface of the plateau is everywhere even and the isolated portions all lie at accordant altitudes. The surface as a whole strikes about 20° north of west and slopes to the north from the most southern exposure to the low area four miles south of Aspen Mountain. There is then a rise toward the north to the base of the mountain. A few elevations will give an idea of the slope of this surface. The highest part of Miller Mountain is, in round numbers, 8,500 feet; Rife Mountain, 8,400 feet; the low area south of Aspen, 7,600; and the plateau at the west base of Aspen, 7,900 feet. Bishop Mountain is considerably higher and the same is true of the southern part of Little Mountain. The slope of the gravel surface is so even, and the accordance in elevation of isolated remnants is so close, that one may stand on the top of one of them and, looking along the strike, see the trees on the top of the others,

[1] A. R. Schultz, "The Southern Part of the Rock Springs Coal Field, Sweetwater Co., Wyo.," *Bull. U.S.G.S. No. 381*, 112.

even when the distance is six or eight miles. No suggestion of the intervening valleys then appears. This close accordance indicates that all the gravel-capped areas once formed parts of the same even plateau-surface and have been separated only by subsequent erosion. The plateau is still in the process of active dissection. Adjacent parts are in many cases separated by valleys over 1,000 feet deep whose tributaries, by working their way back into the plateau by head-water erosion, are responsible for the very irregular ground-plan of the parts still remaining. Fig. 3 gives a good

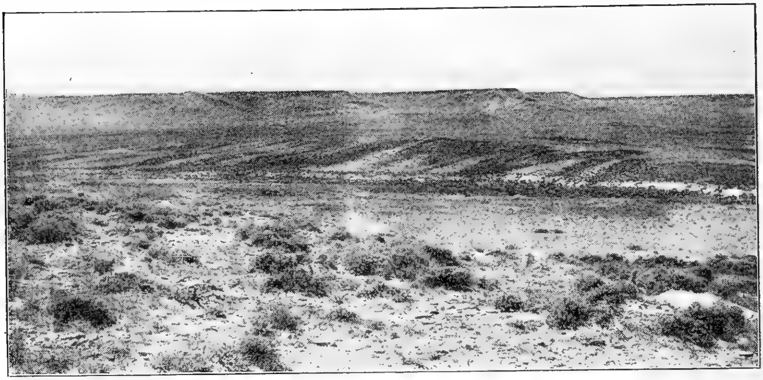

FIG. 3.—Miller Mountain plateau as seen from a distance of four and one-half miles, looking west from the banks of. Salt Wells Creek. Note the even sky-line. The view shows the edge of the plateau for a distance of five miles without disclosing any visible irregularity. The conglomerate capping here averages between fifty and one hundred feet in thickness and is well cemented at the base. The top of the plateau is about 1,000 feet higher than the stream in the foreground. Between the stream and the base of the scarps the wash-apron described on a later page is fairly well shown.

idea of the sky-line of the plateau as seen from a distance of about four miles.

Character of the rock floor of the plateau.—As already stated, the entire plateau is capped by gravels which may be loose and unconsolidated in the upper part but are as a rule firmly cemented at the base. This conglomerate capping varies in thickness from eight to ten feet to as much as two hundred feet in different parts of the area. The rock-surface on which it lies is a very even, beveled rock floor which, though it may be slightly irregular in places, is on the whole remarkably smooth. In no part of the

area studied were noticeable irregularities in the surface evident in the exposed line of contact with the underlying rocks. In several places, but best along the eastern face of Little Mountain, this contact can be seen continuously for several miles, and in all that distance does not display any appreciable irregularity. The probable reason for this great regularity is that the underlying rocks are uniform in texture and quite soft. In localities where the underlying rocks are markedly unequal in hardness the contact is slightly irregular in detail, but still regular in general.

A large part of the gravel-capped plateau lies on the truncated

FIG. 4.—Unconformity of Bishop Conglomerate with underlying Cretaceous rocks southeast of Aspen Mountain. The dark horizontal bed at the top is the conglomerate. Note how evenly the base of this conglomerate truncates the dipping sandstones beneath. This is typical of conditions all along the edge of the plateau.

crest of the Rock Springs dome, a broad anticline of sedimentary rocks about ninety miles in length with the long axis running a little west of north through Aspen Mountain. This anticline has a total width of about forty miles. In the southern part of the area the plateau truncates the tilted rocks on the northern flank of the Uinta uplift. The beveling of the underlying rocks by the plateau-surface is very marked. In certain parts of the Rock Springs dome these underlying rocks dip in both directions from the crest, sometimes at an angle as high as 35°, yet the plateau-surface cuts evenly across them entirely irrespective of structure and almost irrespective of hardness (Fig. 4). Faults and folds in the underlying rocks have no expression in the plateau-surface.

The rock floor of this plateau is clearly a peneplained surface of very considerable extent and great regularity. We are not dealing in this case with an imaginary peneplain whose existence is deduced from the finding of hilltops at about the same level, but with one in which the original planed surface is still preserved over a broad area with its edges exposed and with an evenness the more striking on account of the folded condition of the underlying rocks.

Extent of the peneplain.—The portion of the area mapped in detail in the summer of 1908 in which remnants of the peneplain occur measures about twenty-seven miles from north to south and twenty-two miles from east to west. Including Bishop Mountain and the western part of Little Mountain which were not mapped in detail, but which are without doubt parts of the same peneplain, the dimensions just given will be increased by about ten miles in either direction. This makes an area of at least 1,200 square miles which we can definitely say was reduced to the condition of a peneplain of very slight relief.

There is good evidence that the peneplain had a much greater extent than that indicated by the area over which portions of the gravel-capped plateau still remain; for the lava-sheets of the Leucite Hills, which are scattered over a considerable area from fifteen to forty miles north of Aspen Mountain, lie on the beveled surfaces of the underlying sedimentary rocks. The lava-flows have preserved these beveled surfaces at their original elevations. These, in the case of the larger flows, are so nearly in accord, and so nearly agree with those of the gravel-capped plateaus to the south of Aspen Mountain, that it is reasonably safe to assume that the lavas were poured out on the surface of the same peneplain. The following figures will illustrate this relationship: Approximate elevation of the base of the gravels south of Aspen Mountain, 7,600 feet; base of Pilot Butte lava-flow, 7,900 feet; Zirkel Mesa, 7,600 feet; Steamboat Mountain, forty miles north of Aspen, 8,250 feet; and North Table Mountain, about 8,150 feet. All of these agree in that they, like the plateau to the south, stand from 800 to 1,200 feet above the level of the adjacent valleys. Several of the smaller lava-flows are at lower levels and do not agree closely with those mentioned above. A small flow three miles northwest

of Zirkel Mesa has an elevation of 7,900 feet, 300 feet higher than that of Zirkel. Most of the flows which are discordant are smaller and lower than the average and evidently were poured out after the principal period of extrusion on a surface somewhat reduced by erosion. The larger of the Leucite Hills lava-flows do not differ more among themselves as to elevation than do different parts of the Miller Mountain plateau itself.

Monadnocks.—Aspen Mountain which rises about 1,000 feet above the level of the plateau to the south is a ridge of resistant

FIG. 5.—Antelope Butte, a monadnock on the peneplain southwest of Aspen Mountain as seen from a distance of three and one-half miles. To the right in the middle distance is the head of a stream-valley which is working back into the plateau. This view gives a fair idea of the appearance of the surface of the plateau, though it is here somewhat less even than usual on account of proximity to the invading stream-valley. In the immediate foreground is a smaller monadnock similar to Antelope Butte. (Photo. by A. R. Schultz.)

quartzite formed by the impregnation with silica of a soft Cretaceous sandstone. On account of its superior hardness it stands as a monadnock on the peneplain. From the summit of the mountain there is on the north a steep drop to the lowlands of Bitter Creek, and to the south a gradual slope to the surface of the gravel plateau. At the time of planation Aspen was reduced to a moderate slope. The present steep slope on the north side of the mountain is the result of more recent erosion.

Six miles southwest of Aspen is a much smaller monadnock known as Antelope Butte which rises as a conical hill about 150 feet above the surface of the peneplain. Fig. 5, a view taken

from another small monadnock near the base of Aspen, shows well its character and relation to the surface of the gravels. This, like Aspen, is due to the silicification of a Cretaceous sandstone. Near by there are several other smaller masses of silicified sandstone projecting through the gravels which in this vicinity are comparatively thin, sometimes not more than ten or twelve feet in thickness.

Character and origin of the gravels.—The conglomeratic capping of the plateau is made up for the most part of gravel and sand of greatly varying texture. In the low area south of Aspen Mountain the pebbles are not as a rule more than from one-half to one inch in diameter, and the greater part of the material on the surface is a fine gravel or sandy loam derived from the disintegration of the conglomerate. As one goes south the material gradually becomes coarser till, at the southern end of Miller Mountain, bowlders varying from one to five feet or more in diameter are common. On the south slope of the mountain many large bowlders strew the surface to such an extent that passage with a horse is difficult. From the low area *northward* to Aspen Mountain the material also becomes coarser. In some of the deep gullies cut into this deposit one may find many bowlders like those shown in the photograph, Fig. 6. Diameters of four or five feet are not uncommon in this part of the deposit. The bowlders are subangular for the most part, like those shown in the photograph. They occur imbedded irregularly in finer gravels and sand.

The gravels are rudely stratified, but in ordinary exposures the stratification cannot be seen well. At first the deposit at the base of Aspen was thought to be of glacial origin on account of the large size of the bowlders, their subangular nature, and their occurrence scattered irregularly through the finer gravels. Later this idea was abandoned on account of the complete absence of striations on any of the bowlders, the lack of any signs of glacial action on the bed-rock underneath, and finally on account of the local nature of any possible supply ground. Aspen Mountain from which the material came is too small to have supported glaciers under any circumstances.

South of the low area the gravels consist largely of red and

white quartzites with occasional specimens of gneiss, schist, diabase, and limestone. There can be no doubt as to their origin in the Uinta Mountains to the south where similar rocks are found.

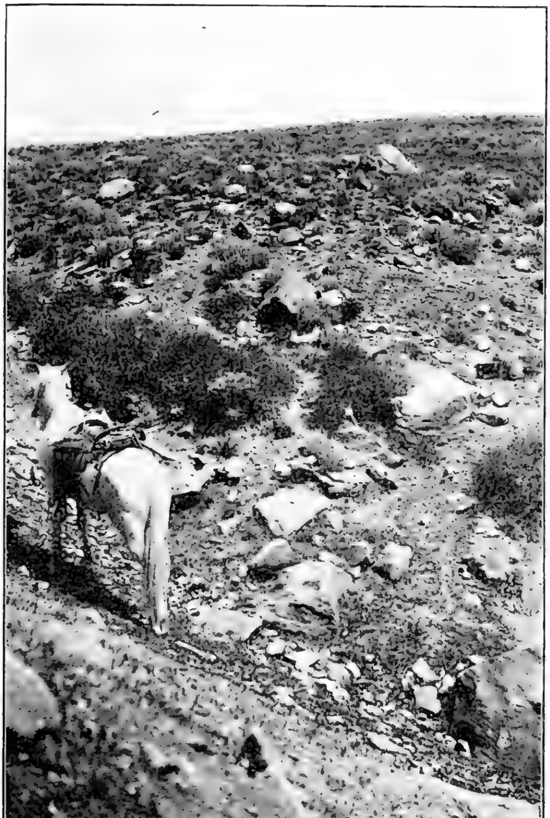

FIG. 6.—Bowlders exposed in a stream-gulley in the Bishop Conglomerate on the southeast flank of Aspen Mountain, well down on the plateau. This is a typical example of the coarser débris which has accumulated round the base of the mountain. It is of local origin, entirely distinct from the Uinta gravels to the south.

This origin is also amply indicated by the fact that the material becomes coarser toward the mountains. North of the low area, round the base of Aspen, the gravel is of local nature, derived from the sandstones and quartzites of the mountain. The surface here

slopes to the south in a direction opposite to that of the portion covered by the Uinta gravels.

The low area referred to is evidently fundamentally of a constructional nature lying at the junction of two fans, the one from the Uinta Mountains, the other from Aspen. Where these fans meet there is a distinct interfingering of the two kinds of gravel. In riding along in an east-and-west direction one is first on Uinta gravels, then on those from Aspen. Areas of one extend out into areas of the other. The vertical interlapping of the two was nowhere seen, though it undoubtedly exists. The whole relation of the two indicates that they were spread out at the same time the one from the Uintas, the other from Aspen Mountain.

INTERPRETATION

Planation.—From the relations just described it is evident that the Rock Springs region has been subjected to a long period of planation during which the surface of the land was reduced to the condition of a peneplain. The rocks were worn down until differences in structure produced no corresponding effect in the topography of the plain. In a few exceptional cases, like those of Aspen Mountain and Antelope Butte, hard rocks remained above the plain as monadnocks. That the plain was of considerable extent is shown by the fact that it covered not only the area south of Rock Springs as far as the Uinta Mountains, but also, as is indicated by the relation of the lava-flows of the Leucite Hills, all the area between the Uintas and the Wind River Mountains 200 miles to the north. Its limits are unknown.

Present differences in elevations of portions of the peneplained surface still remaining indicate that the whole region was reduced to the condition of a gently undulating plain of advanced old age with a relief of 700 to 800 feet in distances of 25 or 30 miles. This conception corresponds well with the observed great regularity of the plain surface in details and its broad irregularity when distances of 25 or 30 miles are considered.

As to the time of planation it is not possible with the information at hand to make any definite statement further than that it was later than the Green River Eocene. There can be no question

of this for along the eastern face of Little Mountain the peneplain truncates rocks of this age. From long-distance observations west of Green River it is thought that the planed surface will be found to truncate rocks of the Bridger formation along the southern rim of the Bridger basin. Gravel-covered, planed surfaces which may have originated at the same time as those of the Rock Springs region are reported by Woodruff[1] from the Wind River basin of Wyoming. The evidence there indicates that the planation was not completed until after the deposition of the White River Oligocene. The fossils in the gravels do not definitely determine the age, but the beds lie above various formations from Colorado up through and including Mesaverde, Cretaceous, and Wind River Eocene, younger than Fort Union. They were not seen in contact with White River beds, but deformations which moved the Wind River beds as well as the White River Oligocene, overlying, occurred previous to the deposition of these gravels, hence the inference that they are younger than White River. If these planed surfaces in the Wind River basin are the result of the same period of planation as those of the Rock Springs region, then the date of this is established with little question as later than White River Oligocene.

In the absence of more definite evidence from the area under discussion we can only assert that the planation took place in the late Tertiary, and that it was doubtless in late Tertiary time that the culmination of the base-leveling process was reached. Further observations in other regions or more extended observations in this region may later make it possible to assign a more definite date for the planation.

For the present discussion we will assume that planation was in progress during the latter part of the Tertiary, and that it ceased with the beginning of the crustal movements which occurred between the Miocene and the Pliocene; the reader meanwhile bearing in mind that this date is merely provisional pending the discovery of more exact data.

Climatic conditions at the time of planation.—Planation over

[1] E. G. Woodruff, unpublished data. See U.S. Geological Survey bulletin on the "Coal Beds of the Wind River Basin, Wyoming," soon to be published.

large areas may be accomplished by any one of three agencies: marine planation, subaërial denudation under conditions of moist climate, or denudation under arid conditions by wind scour. In the case at hand the first of these, marine planation, is thrown out of the question by the broad irregularities of the peneplain and its gently undulating nature, as well as by the improbability of such planation having occurred so far inland in late Tertiary times.

The second explanation, normal peneplanation under a moist climate, accords well with the facts. We find a smooth, yet gently undulating surface with differences in relief amounting to 700 or 800 feet at points twenty-five miles or more apart. This indicates slopes of from ten to thirty feet per mile. These conditions are what should be expected if the peneplain is the result of normal denudation under moist conditions.

In the third place there is the possibility of planation under arid conditions by wind scour. This agency in an arid climate is worthy of serious consideration, for, under favorable conditions, it seems capable of playing a very important rôle in denudation. Passarge has shown that under conditions of long-continued aridity in an inclosed basin remarkably even plains may be developed over large areas by this agency combined with the action of occasional rains, which by washing loose material into the hollows tend to counteract any tendency on the part of the wind toward the formation of basins in the areas of the more easily eroded rocks. Plains of such an origin with harder rock-masses standing above them as "Inselberge" are described from South Africa. In so far as the smooth plain condition and the occurrence of monadnocks projecting above it is concerned the conditions observed in the Rock Springs region agree with the wind-erosion hypothesis. Another condition which is in harmony with this interpretation is that the rock floor of the peneplain underneath the gravels, wherever observed, was found to be fresh and undecayed. There was no evidence of an old soil underlying the gravels such as might be expected if the planation were performed under moist conditions. It is possible however that any old soils which may have been formed were removed during an arid period just preceding the deposition of the gravels.

While the features of the peneplain may be interpreted as due to wind erosion, the writer is inclined to favor the hypothesis of subaërial denudation under moist conditions. The reasons for this preference are as follows: (1) Present conditions in the region indicate only a moderate efficiency of wind erosion. The region at the present time is subjected to desert conditions, though these are not now extreme. The winds are strong and blow almost continually, especially during the day. Wind action is conspicuous in places where conditions are particularly favorable, and a very considerable amount of material is removed in this way, yet the present features of topography are due rather to stream work than to the wind. In places where the streams by cutting have exposed softer rocks and these are of such a nature as to be easily eroded, wind scour is noticeable, but otherwise not. Practically all the details of topography are the result of water action. In southern California where the average rainfall is less than five inches per year the topography is almost entirely the result of stream action. There is even less evidence of wind work than in Wyoming. All the dissection of the mountains is of the type produced by streams and there is little sign of wind erosion. It is true that the winds do pick up and carry away considerable dust at certain times, particularly during dust storms, but their topographic effect as compared with that of desert streams is almost negligible. For these reasons the formation, by wind erosion, of a smooth peneplain like that under discussion seems without parallel in present conditions. (2) The conditions round the base of Aspen Mountain are thought to indicate a moist climate at the time of planation. Those conditions are indicated by the accompanying sketch, Fig. 7. At the time of its development the peneplain extended with gentle slope close up to the base of the mountain. Later, under conditions of undoubted aridity, a mantle of piedmont gravels accumulated round the base of the mountain. Since the arid climate brought about the formation of the wash-apron it would seem that at the time of planation the climate must have been moister, for material resulting from weathering was then removed and the peneplain developed close up to the hard rocks of the mountain.

The basis of the assignment of the accumulation of piedmont

gravels to an arid climate is this—under such conditions whatever rainfall there is usually comes in the form of torrents or cloud-bursts. These give a very heavy precipitation over local areas for a short time, with resulting temporary streams of great transporting power. These occasional torrential rains act on slopes unprotected by vegetation and consequently pick up and carry forward a heavy load of rock-waste. Just as soon as the streams leave the steeper slopes much of this débris must be dropped, and all must come to rest within a comparatively short distance, for the water either sinks into the ground or rapidly evaporates. The consequence of this process is the accumulation of piedmont gravel slopes round the higher lands. Under a moist climate the streams are perma-

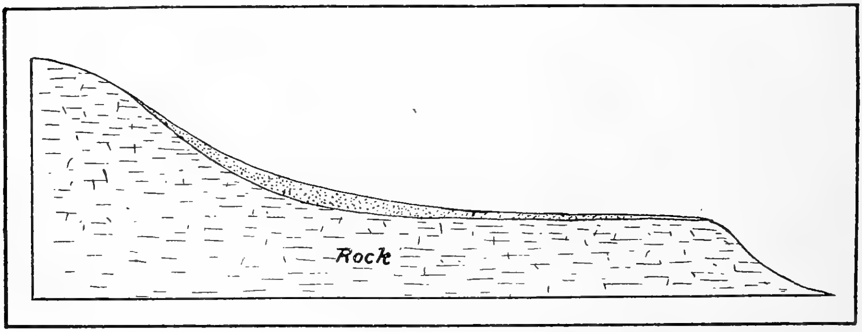

Fig. 7.—Sketch showing conditions round the base of Aspen Mountain. A lens-shaped débris fan mantles the lower slopes.

nent, they work continuously; the slopes are protected by vegetation, hence furnish less débris to the waters of a passing storm. Weathering reduces the rocks to finer particles, which are exported by the ever-flowing streams, consequently degradation rather than aggradation is the rule. It is believed that under these conditions planation, with the removal of the resulting waste, would be pushed close up to the base of the harder rocks.

This, as an explanation of the conditions round Aspen Mountain, is not without its uncertainties, for it might be argued that conditions of extreme aridity might allow the development of a flat or gently sloping plain close up to the base of the mountain by wind erosion. In that case the efficiency of the wind in removing loose débris from round the base of the mountain must have been

greater than that of the temporary streams in loosening and carrying material down the slopes, for any such piedmont débris must be removed before the wind can attack the rocks at the mountain-base. In an absolutely rainless region there would be no difficulty in accepting this explanation, but there seems to be no region which is without its occasional rains, and a slight amount of rainfall distributed as it is in the deserts in the form of local torrents would be sufficient to bring down a considerable quantity of débris from the bare slopes of the mountain—more it would seem than could be effectively disposed of by the wind.

From the foregoing lines of reasoning it is thought that the planation was the result of long-continued subaërial denudation under conditions of a moist climate. This belief is not held with great confidence, however, for it is recognized that desert erosion might under certain conditions produce similar results.

The surface of the gravels, from Miller Mountain northward to near the low area, slopes to the north at the rate of between seventy and one hundred feet per mile. The underlying rock-surface has a slightly lower slope. Judging from the present slope and attitude of the gravel-deposits it seems unlikely that there has been any considerable change in slope of the underlying peneplained surface since they were laid down, though there may have been a general elevation of the whole region. The gravel surface is a graded slope and shows no sign of disturbance since its formation. The transportation of large bowlders such as those on Miller Mountain would require a considerable gradient, probably as great as that at present. On the other hand, the development of a peneplained surface as even as that under discussion would require a more nearly horizontal attitude than at present at the time of planation, at any rate if this were accomplished under conditions of a moist climate, as there seems reason to think was the case. Whether or not such a surface with such a slope could be formed under desert conditions by wind scour is more difficult to determine, but it seems unlikely. The present slope would therefore indicate that, unless planation was the result of wind erosion, this portion of the peneplain when formed was more nearly horizontal than now and that it was tilted toward the north at a time of

renewed uplift of the Uintas immediately antedating the deposition of the gravels.

Cause of the invasion of the gravels.—The gravels which form the capping of the peneplain were, in the southern part of the area, unquestionably derived from the Uintas. During the long period of quiet while the peneplain was developing, any considerable elevations in the Uintas must have been considerably reduced and very possibly planed off to correspond with the character of the adjoining country. At any rate they were not then supplying débris to the adjacent low-lying areas.

In order to bring about the change from these conditions to those which followed, in which great desert fans spread out from the mountains and covered the adjacent plains to distances of from thirty to forty miles or more, there must have been a decided change in the relations of plains and mountains. A change of conditions capable of producing so great results could have been no less than a pronounced renewed uplift of the Uinta mountain-range with the consequent development of extensive débris fans.

As a test of the preceding, let us postulate conditions as they seem to have been at the end of the period of planation, with the whole country, including the Uintas, reduced to low relief and lying at a comparatively low altitude. What then would be the effect of a marked uplift of the mountain-range?

In the first place there would, in all probability, be a marked change in climate. The high mountain-range to the south would cut off some of the moisture-bearing winds; with the result that the adjacent lowlands would become more arid. This effect would be increased if at the same time the Wasatch range, which runs north and south about one hundred miles west of this area, were also elevated so as to cut off the winds from the west. The high lands of the Uintas, attacked by the agencies of denudation and receiving most of the precipitation, would supply to the streams large quantities of rock-waste which, on account of the arid nature of the climate, could not be entirely removed to the sea, but would accumulate at the base of the range in the form of alluvial fans such as are developing at the base of the desert-ranges today. These fans as they grew would gradually spread out over the

peneplain to the north, burying first the region close to the base of the mountains and later that farther away. In the meantime these more distant parts would be exposed to the agencies of an arid climate until the fans finally reached them. We should expect to find then along this outer zone not a deep residual soil formed during the time of planation, but fresh rock floors resulting from exposure to an arid climate before the fans reached so far out.

The effect of an arid climate on a monadnock like Aspen Mountain should be apparent in the mantling of the slopes with débris. This, owing to the lack of a protective covering of vegetation on the slopes, would be comparatively rapidly carried down by the desert torrents and accumulated at the base as has already been suggested. This is the actual condition at the base of Aspen. Starting at the low area and going toward the mountain one finds that the gravel-deposit is all of local nature and gradually thickens till, near the base of the mountain, it has an observed thickness of over two hundred feet and the base was not seen. It thins again as it laps up on the sides of the mountain. The section radially to the mountain is lenticular in form, the bottom corresponding to the rock-slope of Aspen as developed during the time of planation, and the top being graded to the slope of the desert fans, which is considerably more gentle.

The bed-rock in the low area is fresh, as already stated; a condition which agrees equally well with the succession of events just postulated, as with the idea of planation under desert conditions.

The relation of the Miller Mountain gravels to the Uintas corresponds in all respects with what we should expect in the case of gravel fans accumulating at the base of high mountains in an arid climate, not only in the nature of the material in the fans, but also in the distribution and general attitude of the deposits.

Reasoning thus we are led to the conclusion that the period of planation was brought to a close by a renewal of mountain uplift during which the Uintas were greatly elevated with respect to the surrounding plains; that this period of mountain-making was probably followed in this region by a change from a comparatively moist to an arid climate; and that great desert fans of gravel and

sand spread out from the mountains far over the plains, while at the same time smaller fans spread out in like manner from the monadnocks of the plains and merged with the gravels from the mountains.

It seems likely that this mountain uplift was accompanied by tilting of the land for twenty miles or so north of the mountains, for, as stated already, the rock-surface over this area slopes toward the north at the rate of about seventy-five feet per mile; a slope which seems too great to have remained undissected under the conditions of planation.

The Uintas at the time of the deposition of the gravels rose to a much greater height than at present, for to the south of Little Mountain and Miller Mountain the present summits of the range are little if any higher than the base of the gravels on these plateaus. The highest summit north of Green River is about 8,250 feet, while the summit of the plateau at Miller Mountain is 8,500 feet and Little Mountain is still higher. South of the river the mountains are somewhat higher, but even here they are only fron 300 to 1,000 feet above the tops of the gravel-capped plateaus. This in a distance of from fifteen to twenty-five miles gives a slope entirely inadequate for the transportation of the coarse gravel found on Miller Mountain. If the present grade of the gravel surface on Miller Mountain, one hundred feet per mile, were prolonged for fifteen miles it would amount to a rise of 1,500 feet. This is not enough, for the fans were necessarily steeper near the mountains than farther out so that at the very least the mountains must have been 2,000 feet higher than now to give sufficient grade to account for the transportation of the gravels to their present position, and this is not taking into account the still greater elevation necessary to furnish a supply ground for the material of the fan.

The course of Green River during this time of mountain-building cannot be discussed here, as its relation to the gravels close to the base of the mountains is not known to the writer. At present it flows between the gravel-deposits of Miller and Little mountains and the higher parts of the Uintas from which the gravels were derived. We are led then to one of two alternatives: either the river was not flowing in its present course at the time the gravels

were deposited, or the gravels were derived entirely from the part of the mountains north of the river. Further observations will be necessary to determine this point. It is suggested that a study of the relations of the river and gravels in and near the mountains is likely to furnish valuable clues toward the solution of the problem of the history of Green River and its relation to the Uinta Mountain uplift.

In connection with the evidence of the uplift of the Uintas at or near the close of the Miocene it is a significant fact that the lava-flows of the Leucite Hills were spread out on the surface of this Tertiary peneplain. Earth movements of great magnitude such as those responsible for the uplift of the Uintas are likely to be accompanied by volcanic activity, either in the area of uplift or in neighboring regions. With this fact in mind it would seem more than a coincidence that the Leucite Hills lavas were extruded at about the time of the building of the outwash gravel fans from the newly uplifted Uinta Mountains; since both fans and lava-flows lie on the undissected surface of the peneplain. In this connection it is interesting to note that in the Sierra Madre about one hundred miles to the east Ball[1] has found high-level gravels similar to those of the Rock Springs region, in some places overlain by lava-flows.

Studies in the West[2] have shown that the close of the Miocene or more probably the transition period between the Miocene and the Pliocene was a time of extensive mountain uplifts and crustal movements. The Tertiary peneplain of the Colorado valley was, according to Dutton,[3] uplifted at this time. Large parts of the Great Basin and the Sierra Nevada and Cascade mountains were elevated. It was at this time that the topographic features of the West began to take shape somewhat as they are today. There occurred over the whole Cordilleras a regional uplift as well as one of individual mountain-ranges. Coincident with these crustal movements were the great lava-extrusions of the late Miocene.

[1] Max W. Ball, "The Eastern Part of the Little Snake River Coal Field, Wyoming," *U.S.G.S. Bull. 381*.

[2] See Chamberlin and Salisbury, *Text Book of Geology*, III, 274–75, for references.

[3] Dutton, *Monograph II*, U.S. Geol. Survey.

The fact that the succession of events indicated by the gravel-covered peneplain with its associated features, as worked out independently of these other studies, agrees so closely with their results, strengthens the conclusions reached as a result of our local investigation.

PHYSIOGRAPHIC CHANGES SUBSEQUENT TO THE GRAVEL-DEPOSITION

1. *Erosion.*—Practically all the erosion which gives rise to the present diverse topography of the Rock Springs region is subsequent to the deposition of the gravels. Over wide areas these are entirely removed, and wherever present they are merely remnants standing, in general, over 1,000 feet above the major stream-valleys. The present streams, which over the area once covered by the gravels must have been initiated on the gravel surface, are superposed discordantly on the underlying rocks. The minor tributaries are subsequent on the structure, while the major streams are entirely independent of it. In one instance, that of Salt Wells Creek, the stream three times breaks across a scarp over 1,000 feet in height. Wide areas in the softer rocks have been reduced to low relief at elevations from 800 to 1,000 feet below the old peneplain level. Except where protected by lava-flows or the gravels, even the tops of the scarps of harder sandstone are several hundred feet below the peneplain level. All of this erosion has taken place since the deposition of the gravels.

Present denudation is being accomplished by wind and water together. The hardness and position of the rocks are the determining factors in the rate of erosion. In general the harder rocks stand out in the form of scarps. Horizontal rocks have shown greater resistance than the same rocks in an inclined position.

As already pointed out, the Uinta Mountains from which the gravels were derived are now lower than the tops of the gravel-deposits fifteen miles and more away and are separated from them by a valley at least 2,500 feet deep (see photograph, Fig. 8). They must therefore have been subjected either to profound denudation since the gravels were spread out over them, or to downthrow by faulting. If their present low elevation is due to denudation this

must have been relatively much greater than that of the gravel-capped plateaus. This is not unreasonable, for one would expect that denudation would be more effective in the mountains, exposed as they are to the excessive action of frost and wind, with steep slopes and highly inclined rocks, than in an adjacent lower region of nearly horizontal rocks, even though the rocks in the mountains are harder. Then too, in the case of the Uintas, Green River flows through them in a deep canyon. This gives steep slopes and con-

FIG. 8.—A typical exposure of the conglomerate on the south face of Little Mountain. This is a view looking southeast into Red Creek basin, the bottom of which lies some 2,500 feet below. The outlying ranges of the Uintas may be seen in the background to the right. Red Creek valley lies between the plateau and the mountains. This view gives some idea of the character and immense amount of erosion which has been accomplished since the conglomerate was laid down. (Photo. by A. R. Schultz.)

sequently more rapid erosion of the adjacent mountains than of the plateaus farther away. As to the alternative of a downthrow of the mountain-block since the gravels were deposited, there is some uncertainty. The principal uplift of the northern flank of the Uintas took place along a fault whose maximum displacement amounted to over 25,000 feet, but there seems to have been a certain amount of downthrow as well as uplift along this fault-zone. Powell[1] described such a downthrow running in an east-and-west direction south and southeast of our area, which he believed had lowered the mountain-block by from 1,000 to 3,000 feet in various

[1] Powell, *Geology of the Uinta Mountains*, 204–6.

places along the fault-line. This fault is described as displacing beds of the Brown's Park Tertiary, but since these beds have been considered to be of earlier age than the Bishop Conglomerate, there is no evidence to indicate the exact time of the displacement; whether before or after the development of the conglomerates.

It is therefore impossible to determine from the data at hand whether the present low elevation of the eastern end of the Uintas, relative to the gravel plateaus, is the result of down-faulting or of simple denudation, with a more rapid lowering of the tilted rocks close to the deep canyon of Green River than of the gently sloping gravel-capped plateaus farther away. Whatever may be the final decision of this point, there can be no question as to the profound denudation subsequent to the gravel-deposition. Red Creek basin, over 2,500 feet deep, and lying outside of the faulted zone, gives a fair measure of this denudation.

The period of erosion continued until all the valleys of the region were deeper than they are at present, though just how much deeper is not known. This erosion evidently took place under conditions of a moderately moist climate, for great amounts of material have been removed by the rivers. A desert climate favors accumulation rather than removal.

2. *First period of aggradation.*—After this period of degradation there came one of aggradation, during which the valleys were partly filled by deposits of silt and gravel washed down from the valley-sides. On the west side of Salt Wells Creek, along and south of Pretty Water Creek, there is an extensive wash-apron derived from the high, gravel-capped Miller Mountain plateau. This wash-apron mantles the slopes down to the valley-bottom, where it grades into a flat-topped valley-filling which now remains as a distinct terrace about forty feet above the present stream (Fig. 9). This valley-filling must have had a depth of considerably over forty feet, for bed-rock is nowhere exposed in the stream-bottom. At least one hundred feet is thought to be a moderate estimate. There are no wells to indicate its exact depth.

This period of aggradation is referred to a change to a more arid climate than that under which the major erosion was accomplished. Under arid conditions the occasional torrential rains, acting on

slopes unprotected by vegetation, loosen and bring down heavy loads of dêbris, which the streams, on account of their intermittent character and the rapid dissipation of the water after a shower by evaporation and absorption into the dry soil, are unable to carry out of the valleys. The result is the silting up of the valleys and the formation of alluvial fans and wash-aprons on the slopes. On the return to a moister climate the streams become permanent, the land is protected by vegetation, hence furnishes less dêbris to the waters of a passing storm, with the result that the wash-aprons and

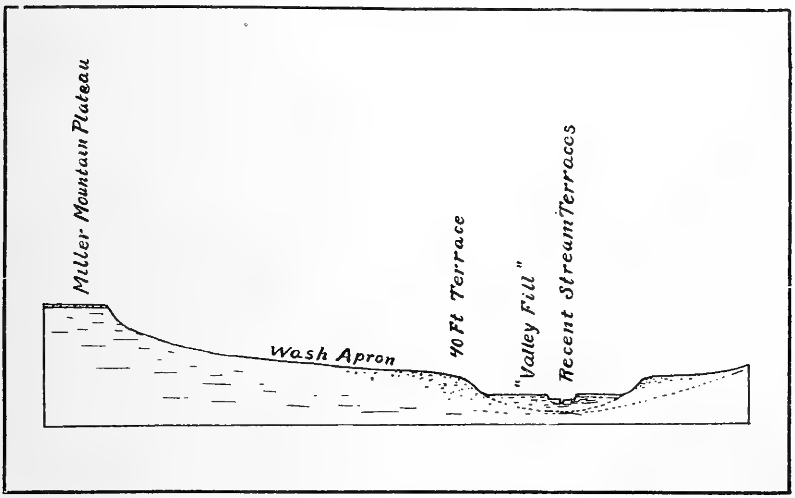

FIG. 9.—Sketch showing conditions along Salt Wells Creek. This sketch shows all the terraces referred to in the text, and their relations to each other and to the Miller Mountain plateau. Vertical scale exaggerated.

silted valleys built up under arid conditions are dissected, leaving gravel terraces along the stream courses.

3. *Erosion.*—Following the preceding stage of desiccation and aggradation there came one of erosion when the wash-aprons were dissected by the streams and the gravel and silt deposited in the central part of the valley were cut down, leaving remnants as flat-topped terraces on either side. This feature is best shown along Salt Wells Creek from the junction of Pretty Water Creek to Chimney Rock, about two and one-half miles to the north. There a cut from one-fourth to one-half mile wide has been made through

the silts and gravels. The resulting terrace is from twenty to forty feet in height and is clearly marked. At the point where the wash-apron feature is best developed, south of Pretty Water Creek, the minor topography is entirely subsequent to the wash-apron, which forms partly dissected, flat divides between the streams. This period of erosion and dissection of the gravels is referred to a cessation of the arid conditions and a return to a moister climate.

4. *Second period of aggradation.*—The full extent of the dissection of the preceding period cannot be seen, for a second period of aggradation has followed and the bottoms of the stream-valleys have again been silted up to an unknown depth. This is the "valley-fill" of the present streams. All the streams, large and small, of the Rock Springs region have this filling which varies, according to the size of the stream, from a few feet to more than a mile in width. The material of this "valley-fill" is a sandy loam with many of the characteristics of loess. It stands up in vertical cliffs along the stream-trenches, sometimes to a height of twenty feet.

The aggradation responsible for this valley-fill is thought to be due without question to a change to more arid climatic conditions. In one of the narrow valleys cut through the high sandstone scarp west of Salt Wells Creek the filling progressed until the bottom of the valley was changed from a graded stream-bed to a series of fans which entirely destroy the grade along the valley-bottom. It is plain that such an effect could be produced only in an arid climate. In this case the valley was small and evidently, during the arid period, could not support even a temporary stream.

5. *Present period of slight dissection.*—In the case of the valley just described the stream is at present cutting through the fans and has almost succeeded in bringing its bed down to grade again. The stream now flows only in times of flood, so that this action is not rapid. All the streams of the region are beginning the dissection of the "valley-fill." Along the larger ones a series of distinct terraces is forming (see Fig. 10). These are migrating up stream. Three terraces in the lower course of a stream give place to two higher up and to a single trench still higher. In several places the mode of retreat was noted. It is by a fall from one or two to five

or six feet in height. All things point toward the conclusion that this dissection is still in progress.

A slight increase in precipitation is thought to be the cause of the dissection. What but a change in the amount of rainfall would account for the building of desert fans across a small stream-valley and their subsequent dissection by the stream?

Confirmative evidence of recent increased precipitation is furnished by a belt of sand dunes about forty miles north of Rock Springs. This belt of dunes begins in the broad plain of the valley of Big Sandy Creek near its junction with Green River, and extends eastward through a low gap in the scarp west of the Leucite Hills,

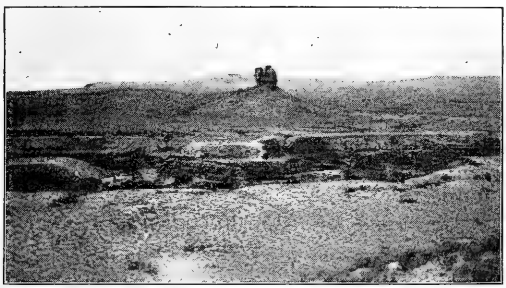

FIG. 10.—Looking across Salt Wells Creek toward Chimney Rock, showing the flat "valley-fill" in which the stream is developing a series of terraces. Three distinct terraces are found at this point. The view gives a good idea of the general character of the flats formed during the latest period of aggradation. Chimney Rock is nearly one-half mile distant, and the flat is here over one-quarter mile in width. (Photo. by B. L. Johnson.)

between two of the larger of these, Steamboat and North Table, and thence eastward across the plain of the Red Desert for many miles. The belt of dune sand varies from one or two to five miles in width. All along the dune strip the vegetation is encroaching on the dunes. In crossing from one side to the other, one passes first an area from one-fourth to one-half mile in width of stagnant, sage-covered dunes, then a belt of active dunes with almost no vegetation, and finally on the other side another belt of sage-covered dunes. West of the pass, on the plains of the Green River valley, the strip of active dunes rapidly narrows to a wedge which pinches out about four miles west of the pass. Here, and farther

west as far as one can see, there is still the dune strip three or four miles wide, but all is covered with vegetation. The irregular dune topography still remains and in places is as well developed as in the area of actively moving sand. Sage brush, often as high as a man's head, covers the dunes.

It is evident that at the time these dunes were forming, the climatic conditions must have been different than at present. A change, either to greater precipitation or lowered mean temperature, or both, with consequent lessened evaporation, would allow vegetation to gain a foothold on the dunes.

This, taken in connection with the fact that the streams are now dissecting the valley-filling formed during a previous dry period, is strong evidence of recent increased precipitation, or, what amounts to the same thing, a cooler climate with lessened evaporation.

It might perhaps be argued that the series of terraces found along the streams could be due to changes in level of the land rather than to changes in climatic conditions. To account for the terraces on this basis would necessitate the following series of crustal movements: First, elevation during the first great erosion; second, depression to account for the first period of aggradation; third, elevation to account for the second period of erosion below the bottoms of the present streams; fourth, depression to account for the second period of aggradation and the formation of the "valley-fill"; and fifth, another slight elevation giving rise to the present stream-trenching. Such an explanation necessitates too many unproved crustal movements.

Relative lengths of the periods of terrace-formation.—It must not be supposed that all these different periods of aggradation and dissection were of equal duration or importance. By far the most important event since the deposition of the high-level gravels was the long cycle of erosion which produced the dominant features of the present topography. All the later terraces are minor features developed within the larger valleys resulting from this great erosion, and represent comparatively recent climatic fluctuations. Fluctuations of equal or greater magnitude might have occurred while the great erosion was in progress without leaving any surviving record.

Comparison of other observations bearing on the problems presented in this paper.—Both King[1] and Powell[2] described the high-level gravels of this region—King, under the name of Wyoming Conglomerate, and Powell under that of Bishop Mountain Conglomerate. Powell recognized the true nature of the gravels as well as the peneplained surface on which they lie. He writes:

> The Bishop Mountain Conglomerate is found at different places to lie unconformably upon every group of the table which is represented in the Uinta Mountains and adjacent country. Its plane of demarkation represents a cessation of the movements of displacement in the region over which it is found, and that the same region was planed down to a base-level of erosion, which base-level was continued during the accumulation of these beds, for it is believed to be a subaërial conglomerate; but should further evidence prove it to be a subaqueous accumulation the plane of separation would then represent an epoch of change from a period of erosion to a period of deposition.[3]

As to the mode of accumulation he has this to say:

> I think that many geologists would ascribe this conglomerate to the action of ice, but throughout all that portion of the Rocky Mountain region which I have studied, I have so frequently found gravels and conglomerates of subaërial origin, and have in so many cases found reason to change my opinion concerning them, often having attributed a driftlike deposit to glacial action, and afterward, on further study, abandoned the theory, being able to demonstrate its subaërial origin, and witnessing on every hand the accumulation of such gravels in valleys and over plains where mountains rise to higher altitudes on either side, and having in so many cases actually seen the cliffs breaking down and the gravels rolling out on the floods of a storm, I am not willing to disregard explanations so obvious and so certain for an extraordinary and more violent hypothesis.[4]

Hayden in connection with his "Survey of the Territories"[5] reports high-level gravel-deposits similar to those of Miller Mountain as occurring on Table Mountain, an isolated butte southeast of the Wind River range; in the valley of South Pass; and along the

[1] Clarence King, *Explorations of the 40th Parallel.*

[2] J. W. Powell, *Geology of the Uinta Mountains*, U.S. Geol. and Geog. Survey, Division II.

[3] J. W. Powell, *Geology of the Uinta Mountains*, 62.

[4] *Ibid.*, 170.

[5] Hayden, *U.S. Geol. and Geog. Survey of the Territories of Idaho and Wyoming, 1877*, 133.

Seminole Mountains. Darton[1] describes flat-topped deposits of coarse conglomerate capping some of the higher divides of the Bighorn Mountains of Wyoming. As already stated, Woodruff[2] finds similar gravels in the Wind River basin, and Ball along the flanks of the Sierra Madre. It is highly probable that further work will demonstrate that all these deposits are genetically related and are the results of the same set of widespread physical conditions.

The later stream-terraces developed in the valleys of the Rock Springs region are thought to be susceptible of correlation with the fluctuations in size of the lakes of the Great Basin, particularly of Lake Bonneville as worked out by Gilbert.[3] Gilbert's succession follows:

1. Pre-Bonneville low-water epoch. This was of long duration.
2. First epoch of high water.
3. Interval of low water, probably with complete desiccation.
4. Second epoch of high water. This was only about one-fifth as long as the first of the high-water epochs.
5. Post-Bonneville epoch of low water, continuing until recent times.

When the succession worked out from the Rock Springs stream-terraces is compared with this it is found that, beginning with the present and working backward, the long period of erosion following the deposition of the high-level gravels on the plateau includes Gilbert's first epoch of high water. From that to the present the two agree closely, the periods of aggradation corresponding to the epochs of desiccation of the lakes, and periods of erosion corresponding with the epochs of high water.

It is believed that, as in the case of the Great Basin lakes, the climatic changes recorded by the stream-terraces are to be correlated with those of the Pleistocene glacial epochs. No glaciers invaded any part of the drainage-area of the Rock Springs region, consequently *the evidence furnished by stream-terraces is entirely free from complications arising from the presence of outwash glacial gravels.*

[1] N. H. Darton, *U.S. Geol. Survey, Professional Paper No. 51*, 67–70.

[2] *Loc. cit.*

[3] G. K. Gilbert, "Lake Bonneville," *U.S. Geol. Survey, Monograph 1.*

SUMMARY

The succession of events indicated by this study is as follows:

1. *Planation*, in progress during the latter part of the Tertiary, reduced the Rock Springs region, including all the area from the Uinta Mountains to the northern end of the Leucite Hills, to the condition of a peneplain of very even surface surmounted by a few small monadnocks of especially resistant rocks. This peneplain is possibly to be correlated with that of the high plateau country to the south in Utah and Arizona.

2. *Mountain-building.*—Pronounced orogenic movements in the late Miocene or early Pliocene brought the foregoing period of planation to a close. These movements resulted in a very considerable renewed uplift along the Uinta mountain-range and a general elevation of the whole region. A change to a more arid climate than formerly is also indicated. Extensive waste slopes or desert alluvial fans were developed round the base of the mountains, and spread far out over the adjacent plains. A remnant of this desert-fan deposit forms the Bishop Conglomerate described in this paper.

3. *Erosion.*—A long period of erosion, probably with a moderately moist climate and relatively steep stream-grades, gave rise to the present diverse topography. Subsequent to the deposition of the gravels, erosion or faulting reduced the height of the Uintas so much that parts of the mountains which must have supplied the gravels now lie at levels lower than the tops of the gravel-beds fifteen to twenty miles away.

4. *Aggradation.*—A change to arid climate brought about a cessation of erosion and a change to conditions of aggradation. The stream-valleys were silted up, and extensive wash-aprons developed at the base of the steeper slopes.

5. *Erosion.*—A return to moister climate resulted in the partial dissection of these wash-aprons and valley-gravels, producing terraces along the valley-sides.

6. *Aggradation.*—Another change to aridity resulted in the formation of the "valley-fill" of the present streams. Some smaller stream-valleys with steep side slopes were partially choked and the stream-grade destroyed by desert fans.

7. *Erosion.*—A recent slight increase in precipitation is indicated by the renewed cutting by the streams and by encroachment of vegetation on the sand dunes.

Conclusion.—In conclusion it is suggested that future correlations of the high-level conglomerates, as well as of the later terraces in the stream-valleys, can be most satisfactorily made on a genetic basis. It will, in most cases, be impossible to trace these features from one drainage-system to another directly. The only basis for comparison is that, in general, like conditions will produce like results, and if the conditions affect large areas, as for instance climatic changes or great periods of planation or mountain-building, their results will be equally widespread.

CONTRIBUTION TO THE PETROGRAPHY OF THE KEWEENAWAN[1]

FRANK F. GROUT
University of Minnesota

OUTLINE

INTRODUCTION

The effusive and clastic rocks of the southwestern extreme of the Keweenawan area, reaching into Minnesota, have been the subject of new study, more detailed than is reported in previous papers.[2] The main results are of two kinds, detail of outcrops, and a laboratory study of rock types and minerals, the latter of more general interest than the former. The new detail reveals no great error in the general maps recently published, but the map here presented shows the

[1] By permission of the Minnesota Geologic and Natural History Survey.

[2] R. D. Irving, "Copper-bearing Rocks of Lake Superior," *U.S.G.S. Mon. V;* Warren Upham and N. H. Winchell, *Minnesota Geol. and Nat. Hist. Survey,* II and IV (county reports); C. P. Berkey, "The Geology of the St. Croix Dalles," *American Geologist* (1897); C. W. Hall, "The Keweenawan Area of Eastern Minnesota," *Bull. Geol. Soc. Am.,* XII, 313.

region of new work, the exposures northeast of Kettle River being now mapped for the first time. The Keweenawan extends not over thirty miles west of the state line, and seventy miles north and south. Maps on a more accurate scale will be given in the reports of the survey when published.

Acknowledgments are due to Professor C. W. Hall for the conception of the work, and to Messrs. A. W. Johnston and W. Yeaton for field assistance.

GEOLOGY

Surficial.—No detailed attention was given to the glacial features of the area, but in passing, it was seen that a great moraine occupied the southeastern side of Pine County, and that the tributaries of the St. Croix River cut through a great thickness of red sandy gravel. From this red drift, just south of the St. Croix, Dr. Berkey describes a laminated red clay, from the study of which he draws important conclusions as to the years that elapsed between two advances of glacial ice. No greater exposures were found than those described by Dr. Berkey, but the boundary including all such clays found in Minnesota indicates that the area is about four times as great as he explored (see Fig. 1).

Relations.—To the south, Upper Cambrian sediments lie unconformably over the lavas of the Keweenawan. To the west and north, the lavas are in contact with more indurated sandstone, in a fault, the mapping of which has not been much altered by the discovery of new exposures. The correlation of the sandstone south on the St. Croix, with that northwest of the fault, is considered safe, but left uncertain by the fact that fossils are not known from the latter, by the unknown extent of the faulting movement, and even the direction of that movement. The dip of both sandstone and lava for several miles from the fault is southeasterly, as would be expected from an elevation of the sandstone, but observations close to the fault are few, and the rocks in these cases badly shattered. When the same contact is traced northeast into Wisconsin, clearer evidence points to a depression of the sandstone, and this is probably the best evidence of conditions in Minnesota.

Structure.—Within the Keweenawan some of the structure is equally uncertain on account of the scarcity of good exposures.

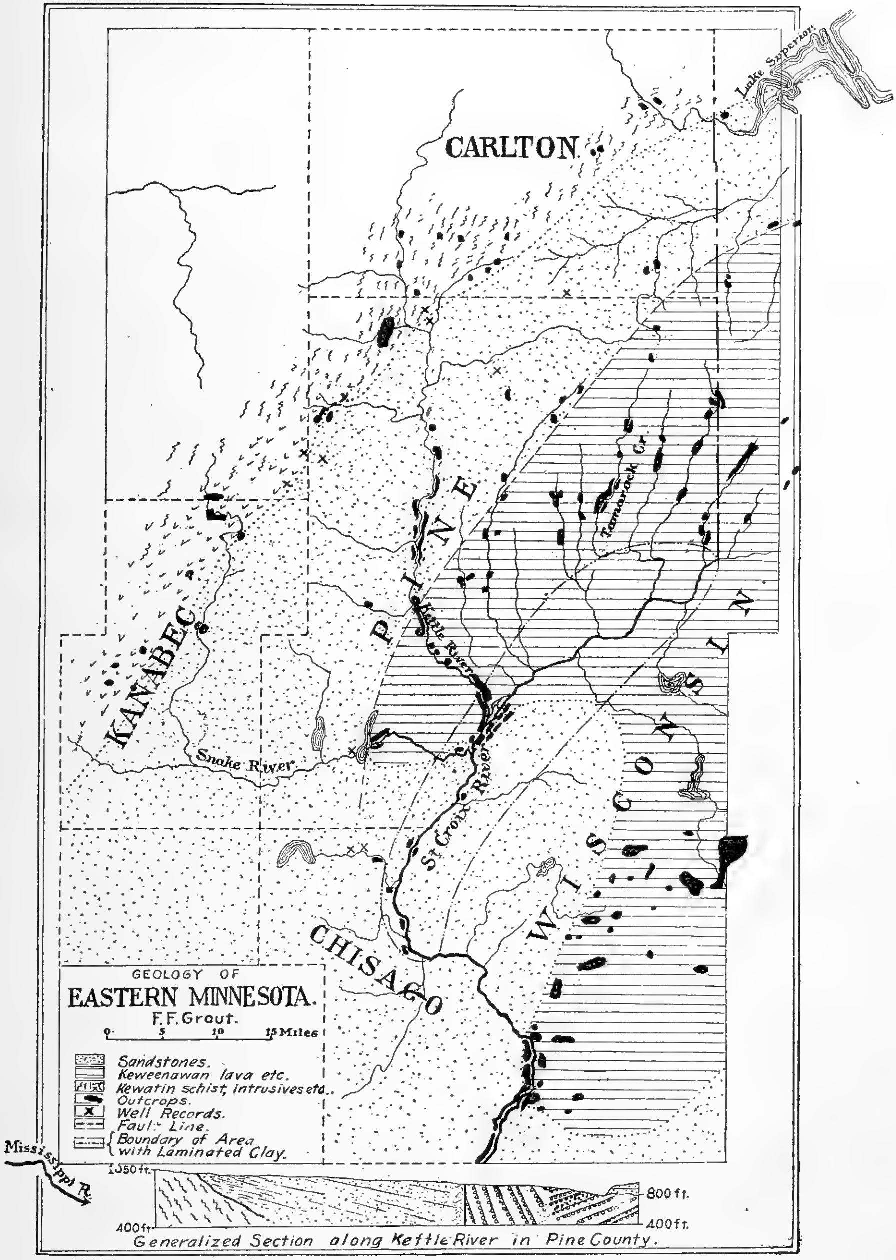

FIG. 1.—Map of eastern Minnesota and part of Wisconsin, showing outcrops and general geology.

Petrographically there is little that is new to the Keweenawan. The greater part of the rock originally occurred in surface flows, with an occasional conglomerate apparently formed along some shoreline. Beds of tuff, derived from volcanic ash and breccias, are not numerous, but are prominent in a few places. Intrusive dikes were not identified in this area. Evidence of the effusive nature of the rocks lies not so much in flowage structures as in the regular sequence of textures—a compact aphanitic basal portion grading into the

FIG. 2.—Ditch at Pine City, Minn., showing lava flows dipping 67°. Flows may be distinguished by the changes of the jointing in the amygdaloid.

coarser body of the flow, with often a characteristic amygdaloid breccia or ash bed before the next flow repeats the series. The jointing is in most places irregular, but in some columnar, as, for example, that producing the Devil's Chair at the Dalles of the St. Croix. The main jointing seldom persists into the amygdaloid, thus giving another means of distinguishing successive flows (see Fig. 2). The chief evidence of faulting is the development of slickensides in several places, and these may be along very minor fractures due to the extensive tilting of so thick a formation. There are no signs of the erratic discontinuance of a flow, or a shifting of position. Spheroidal weathering is quite common. Exceptional structures

develop locally; e.g., a banding simulating gneissic structure in a flow on Snake River, and a schistose streak a few inches wide in a flow seen by Berkey at Taylors Falls.

Near the fault the strike of the flows follows the fault quite closely. The general structure is a complex syncline. Beginning at the south, it is clear that the axis of the syncline must pass between the Taylors Falls rocks, dipping 15 degrees south, 70 degrees west, and the Snake River series, dipping 70 degrees south, 80 degrees east. On Kettle River the axis of the syncline is located within a few hundred paces. The flows farthest up the river, near the fault, dip 50 degrees south, 70 degrees east, and near the mouth other flows dip 20 degrees north, 70 degrees west. Near Kettle River the strike changes rather abruptly, swinging more easterly as one follows a flow northward. In this northeastern area no dip of more than 45 degrees was observed and no outcrop was found southeast of the synclinal axis. Some observations, however, indicate the proximity of the axis. In Wisconsin the axis was sketched by the early geologists,[1] running southwest close to the St. Croix, for a long distance, always on the Wisconsin side. To connect their observations with those on Kettle River requires a double curve in the axis, crossing the St. Croix near the mouth of Tamarack Creek. An alternative might be the suggestion that the sharp fold on Snake River, which becomes less sharp on Kettle River and still less on the next stream, gradually disappears to the northeast; and the whole may be a secondary fold in the northwest limb of the main Keweenawan syncline, which would then be nearly as Irving sketched it. No correlation of beds across the syncline has been possible. In the clear exposures of Kettle River series, several conglomerates are seen on the southeast and none on the northwest, but this may be an accidental disagreement in an incomplete series, because conglomerates are known on Snake River, west of the syncline.

Areal.—The map (Fig. 1) shows the general region of outcrops. The three main types of lava distinguished in this paper are widely distributed and it cannot be said that any one of them is absent in any of the extensive series. Exposures are hardly clear enough to note any change in the general character from the earliest to the

[1] *U.S.G.S. Mon. V.*

latest flow exposed. About three strikingly peculiar types occurred in a few isolated outcrops and not elsewhere in the series. A line connecting the outcrops of a single type proves to run due northeast, conforming to the observed strike near by. Such data furnish the best evidence in Minnesota that a single flow is continuous for over 25 miles. The red laumontite pseudo-amygdaloid is so traced, and within two miles across the strike a highly porphyritic type runs parallel with it.

Geographically the area may be briefly summarized. The Taylors Falls and Snake River districts are discussed in earlier publications, but the remarkable freshness of one of the Snake River rocks is worthy of further mention. In the new area studied there are a few local variations. Most of the exposures are along creek banks. The rock types seen on the western side of the syncline on Kettle River are found due northeast on the smaller creeks. These types include the red pseudo-amygdaloid and a highly porphyritic rock on each creek. Along the lower parts of the eastern creeks the types vary somewhat, but seem to be local modifications rather than evidence of extensive changes of nature.

ECONOMIC.—Copper is found in small amounts in test pits on all the easily accessible streams. Its association varies—on Snake River where most explored, it is in laumontite, and on Kettle River, in prehnite. Some nice specimens are produced. In connection with the chemical side of this study of rocks, it was discovered that the fresh trap rock was the source of the copper. Indications are that the original lavas contained from 0.01 to 0.03 per cent of copper.

PETROGRAPHY

REVIEW.—Descriptions of Keweenawan rocks written between thirty and forty years ago have not been seriously questioned, though the method of naming rocks has developed greatly. All attempts, including this one, result in complex statements referring partly to original conditions, and partly to present altered ones. A summary and correlation of rock-names, in the literature, is given by A. N. Winchell,[1] so that the full list will be omitted.

Chemical data have been presented, in addition to field and micro-

[1] *Journal of Geology*, XVI, 765.

scopic results, by several authors, but only a few analyses are satisfactory for the application of chemical classification. These ancient basic rocks are so far altered in most places that the original can be only roughly estimated from the present composition. However, it seems clear that alteration results differently in different cases, and the average of several tests of a rock-type will give valuable indications of the quality of the magma. It is therefore worth while to

FIG. 3.—Weathered volcanic breccia. About one-half natural size

extend the chemical work, especially when material is very fresh, and analyses can be made quite complete.

CLASTIC ROCKS.—The conglomerates of this area have all been described in earlier papers and need no comment except that no correlation of beds has been possible, and that they give evidence that the bowlders were derived from both Keweenawan and older formations.

Tuff and breccia, of the type found by Dr. Berkey at Taylors Falls, was found on the two tributaries of Tamarack Creek (Fig. 3).

The breccia consists of angular fragments of amygdaloid suspended in a fine-grained fragmental matrix identical with the tuff; and not, as suggested by Dr. Berkey, suspended in the flowing lava or cemented by igneous material. The tuff is fine grained in most places, and the fragments angular; though rounded grains and water-sorting are not difficult to find. Alteration has produced a hard mass of quartz and epidote, an almost indestructible rock. Tuffs and breccias mark the boundary zone between two flows, though in a few cases fragments have been suspended in a later flow.

TYPES OF IGNEOUS ROCKS.—The rock-types described and pictured by earlier writers on the Keweenawan are not all represented in the lavas of eastern Minnesota. In fact, so few are represented that it is unnecessary to use as elaborate a table as A. N. Winchell presents in correlation of the early work. Of his types, based on modern petrographic usage, the area furnishes diabase and olivine diabase with some approaches to basalt and augite andesite, and the corresponding porphyries. In all the sections examined the essential of diabasic or ophitic texture was observed, viz., *the plagioclase needles formed before the augite.* This approaches a granular texture when augite is neither abundant nor coarse grained, but if the fundamental fact be kept in mind, all may be classed as modifications of diabase. No distinction is here drawn between augite and diallage; the presence or absence of olivine is of secondary importance like that of magnetite. The variation of the rock (or its alteration) is evidenced by the range in silica from 42 to 65 per cent. If reference is limited to this Minnesota area, the varieties are more clearly classified by varying texture than by the presence of olivine or other characters suggested by Mr. Winchell. The prevalent diabase is a quite uniform, compact rock with hackly fracture, coarse to fine grained (Fig. 4), grading, on one hand, by all degrees into a rock that is strongly luster-mottled (Fig. 5), also coarse to fine; and on the other hand, into a rock with clearly conchoidal fracture (Fig. 6), often red in color and usually fine grained. These field distinctions correspond to microscopic variations given below. They are to be correlated with Irving's "ordinary," "olivinitic," and "ash-bed" diabase, respectively, but are all included in Winchell's diabase and olivine diabase. All are easily accessible near Pine City, Minnesota.

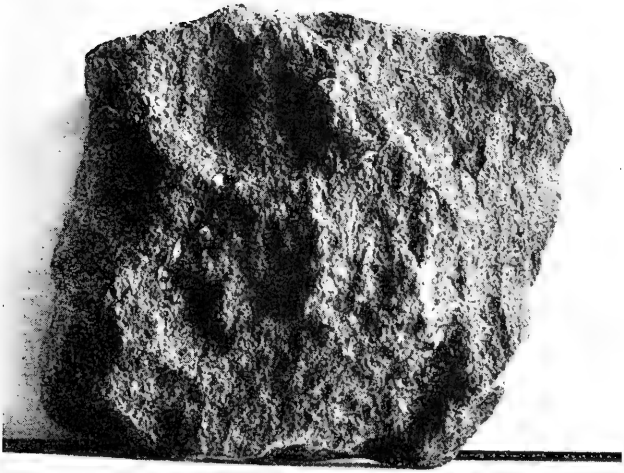

FIG. 4.—The common type of diabase showing hackly fracture. About one-half natural size.

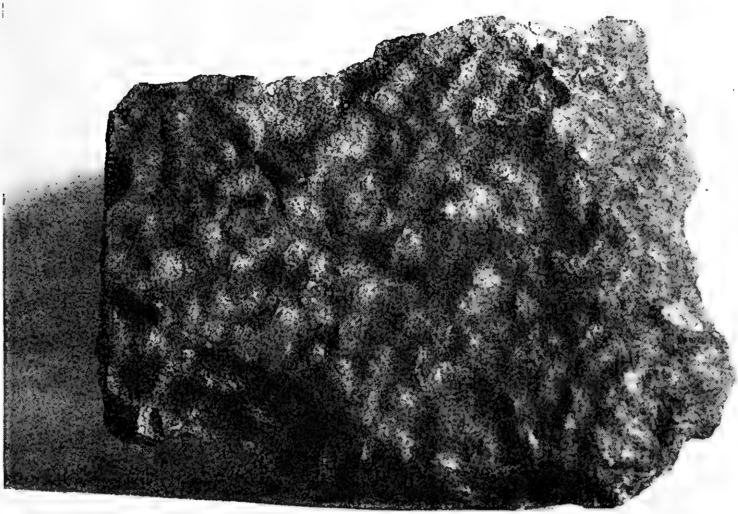

FIG. 5.—The weathered surface of luster-mottled diabase. About one-half natural size.

Mottled diabase.—This is probably the most easily recognized by the unskilled, from the fact that it invariably weathers to a color-mottling, and usually to pits or projections on the surface (Fig. 5). Colors depend upon the conditions of weathering. As a rule, the flows are thick, many of them weather spheroidally, and the amygdaloidal zone is not prominent. The latter point has made some occurrences seem more like intrusive than extrusive rock, but no such conclusion is forced upon one, here. Pumpelly's early description[1] has been widely accepted and its outline of the development of the rock is probably correct. He clearly presents the appearance of

FIG. 6.—Conchoidally fracturing diabase. About one-half natural size

ophitic texture and the resultant luster-mottling. The original rock is reported as containing augite, plagioclase, olivine, and magnetite, with evidences of glassy matrix. Apatite is rarely seen. Alteration yields many other minerals. Of the fifty Minnesota rocks of this type, recently examined in detail, only one section revealed olivine cores of a size and freshness to yield an interference figure; but nearly all were well supplied with pseudomorphs, so similar to the fresh olivine as to be quite unquestionable, though the material was fibrous and pleochroic. Opaque minerals develop along the borders and cracks of the original grains, giving the impression of high relief to the alteration products, chlorite, serpentine, and iddingsite.

Magnetite is abundant in all sections. Hematite is prominent

[1] R. Pumpelly, *Geology of Wisconsin*, III, 33.

in some sections, chlorite in others, but the two seldom develop together.

The plagioclase is labradorite as determined by the maximum extinction angles, in sections perpendicular to the albite twinning. Zonal growth is not rare. The alteration of the feldspar is rather different from the average case described by Pumpelly. Prehnite is not a common product. Aside from a general dusty appearance, a granular light-green mineral develops in the central zone as if it were more easily altered than the outer zone. In extreme cases a complete pseudomorph results, faintly outlined in a ground-mass of no more definite character, and in the aggregate chlorite and orthoclase are indicated by analyses, if not optically. In a few cases secondary orthoclase crystals were identified. In a rather different alteration chlorite or some other green fibers grow up beside the feldspar as radiating groups, which encroach upon the lathlike grains, destroying their form and building a pseudo-amygdule.

Phenocrysts of plagioclase are neither common nor very large in the mottled rocks. When they appear, the composition is similar to that of the smaller crystals.

Augite is gray to brown, rarely showing the color due to titanium. It is one of the last minerals to be affected by alteration, which usually results in the borders becoming dark and dusty with chlorite. Rarely a pseudomorph occurs, light green, pleochroic, and with the extinction angles of hornblende.

In the coarser, fresher sections, the minerals that have been identified fill the space so completely that no room is left for glassy matrix, and none of the secondary products give the impression of resulting from such glass, or occupying its place. In the finer-grained parts of a flow—as near its base—a glass might be more probable, but even here are seen only the extreme alteration products and very little structure to indicate an original glassy condition. Another line of reasoning runs against the probability of much glassy matrix. Augite here appears to be one of the late crystallizations from the magma, and this mineral is commonly classed as a eutectic.[1] Hence it would begin to crystallize only after all those materials had separated, which made the fluid incapable of forming augite alone. It is hard to

[1] Cf. A. C. Lane, *Journal of Geology*, XII, 87–88.

understand how a matrix of the composition of augite should develop first some large crystals of that mineral, and later a glass of the same composition. The chlorite-like mineral which Pumpelly refers to glass, is admitted to be with difficulty distinguished from other chlorite in the rock.

TABLE I

ANALYSES OF MOTTLED DIABASES

1. Original type locality, Greenstone of Keweenaw Point, Mich. George Steiger, analyst. *Journal of Geology*, XVI, 765.
2. Taylors Falls, Minn., along railway track. F. F. Grout, analyst.
3. Tamarack Falls, Tamarack Creek, Pine Co., Minn. F. F. Grout, analyst.
4. Upper Tamarack Creek, Minn. Weathered red. A. W. Johnston, analyst.
5. Upper Tamarack Creek, Minn. Weathered green. A. W. Johnston, analyst.

	1	2	3	4	5
SiO_2	47.69	48.88	47.82	48.07	46.99
Al_2O_3	16.02	16.39	18.52	19.02	21.15
Fe_2O_3	2.41	5.51	6.39	7.65	7.14
FeO	8.70	7.21	3.15	4.83	3.94
MgO	8.31	5.80+	8.20	3.30	2.73−
CaO	10.54	9.11	11.09	9.84	2.17
Na_2O	2.44	2.08	1.67	2.84	0.80
K_2O	none	0.47	0.17	0.63	6.12
H_2O-	0.44	0.19	0.66	0.43	1.30
H_2O+	2.04	2.15	1.53	1.69	6.32
TiO_2	1.38	1.84	0.78	1.72	0.92
CO_2	none	0.09	0.17	none	none
P_2O_5	0.06	0.10	0.05	none	0.56
S	none	0.05	0.04	0.11	0.14
CuO	....	0.02	trace	....	....
MnO	0.26	0.15	0.12	0.21	0.12
BaO	none	0.02	0.02	0.02	none
SrO	none	none	none	0.02	0.03
Cr_2O_3	....	none	0.03	0.18	0.06
	100.29	100.06	100.41	100.56	100.49
Specific gravity	....	2.974	2.898	....	....
	*Auvergnose	Hessose	Hessose	Hessose	....

* For the significance of these names see *Journal of Geology*, X, 555.

The alteration was Pumpelly's special study[1] and proved interesting and complex. For details of the several successive changes, reference must be had to the original. The chloritic minerals are of greatest interest, and their nature is variable in each of the several types of occurrence, as shown below.

[1] R. Pumpelly, *Proc. Am. Acad. Arts and Sciences*, XIII, 253.

The composition of the mottled type is indicated by the analyses of Table I, but each of the Minnesota samples is considerably altered. Nevertheless the calculated norm confirms the field conclusion that there was considerable variation in the proportion of minerals in the originals, and even some variety in the composition of some of the silicates.

Hackly diabase.—Microscopically these rocks are usually coarse grained but mineralogically similar to the mottled type. The texture is diabasic as distinct from ophitic, though intermediate textures are not rare. Many of the flows have well-defined amygdaloidal zones. Pumpelly's study of the metasomatic development of secondary minerals has been checked, as far as material was available, and Minnesota furnishes one type which he did not find well developed—the laumontite rocks.

Olivine was found in sections from one flow of hackly rock in Minnesota. Pseudomorphs, clearly from olivine, were found in about half the sections of this type; but some rocks, closely resembling these, showed no product or structure indicating that olivine had ever been present. The one Minnesota rock showing fresh olivine is so fresh compared with other flows of the region as to be hard to place with them, but there is no sign of mottling, and the texture is far from the typical ophitic. It gave Analysis 3, of Table II. The olivine is just beginning to alter along the borders and cracks to a chloritic mineral of strong pleochroism in brown and green. A little chlorite appears in other parts of the rock, but no room is left for any glass or its alteration products. This occurrence may well be substituted, in general discussions of the Keweenawan, for the type locality given in Michigan, No. 87 of Marvine's Eagle River section. However, it is not suggested that all hackly diabases were olivinitic. Olivine is present in this freshest sample, and its presence or absence is not a good point to use as a type characteristic. The pseudomorphs after olivine vary as before, and the development of magnetite and hematite along the cracks gives the pseudomorph the appearance of the high relief of olivine, in fully half the sections examined. Some of the pseudomorphs give a uniaxial figure, as recorded by Pumpelly.

In the fresh flow of the Snake River series, labradorite is the feldspar, but in the more altered samples very few crystals are fresh

enough to show twinning bands. In these the extinction is wavy and angles are low. Both oligoclase and orthoclase are probable.

Magnetite is seen in all sections and apatite in only one.

Alteration in most cases has proceeded even farther than in the mottled rocks, and resulted in a pseudo-amygdaloid—a botchy mass of secondary minerals. The original texture is revealed by some pseudomorphs, one of the most peculiar being a nearly opaque yellowish-green earth with the form of plagioclase. However, the pseudo-amygdules are quite abundant, developing from any spot as a nucleus, and expanding as they replace the surroundings with a new layer. Chlorite is the commonest material, varying from colorless to dark blue-green, or yellow, or brown, or gray, and usually spherulitic. In similar position in other rocks are calcite, quartz, epidote, actinolite, and a dusty red mineral of very feeble birefringence, which may be laumontite or some other zeolite. Regarding the development of most of these, reference must be had to Pumpelly's paper, but some new work is here offered regarding the laumontite rocks. There is an extensive development of this mineral in some amygdaloidal and vein cavities on Snake River in Minnesota. Its properties are given below with those of other amygdules. Beginning at Kettle River and extending twenty-five miles northeast, is a series of outcrops of a red pseudo-amygdaloid, associated with which are real amygdaloids with red laumontite. The red material of the pseudo-amygdules appears to be similar to that of the amygdules, but the rocks are badly softened and microscopic examination is not very satisfactory. A specific gravity separation of the rock-constituents yielded rather mixed material, the lightest fraction being strongest red in color. Chemical tests of the two lightest fractions show that there is an approach to laumontite (Analyses 4 and 5, Table VI), and there is no doubt that this mineral has developed in the rock-matrix as well as in the cavities. Pumpelly suggests the possibility, and thinks it an early product in the alteration. Its associates here are badly altered; only augite, of the original, is still recognizable in the mass, which affords clear evidence of its original texture.

An entirely distinct line of chemical work has given a hint of the history of some of the rocks. This is the composition of the product

of alteration of laumontite. Where excellent crystals of laumontite are found on Snake River, some perfect pseudomorphs were found with an entire change in certain constituents. Lime is lacking in the secondary mineral and potassium is prominent. In several parts of the area amygdules were found of similar character to this pseudomorph, and an analysis shows the chemical constituents to be similar. This development of a potassium mineral may not be a conclusive proof of the former presence of laumontite, but adds probability to the idea. In other places and other rocks, the potassium minerals found have very different characters. Further, on Upper Tamarack Creek this same mineral is largely developed with chlorite in a pseudo-amygdaloid, which may be a late derivative of the laumontite pseudo-amygdaloid. Analyses of these minerals are given in Table VI, but of the rocks in Table II.

TABLE II

ANALYSES OF HACKLY FRACTURING DIABASES

1. Taylors Falls, Minn. Rather fine grained. C. A. Taylor, student analyst.
2. Crooked Creek, Pine Co., Minn. C. Tronson, student analyst.
3. Pine City, Minn. Coarse and fresh. F. F. Grout, analyst.
4., 5., 6. Altered hackly diabase, forming a belt of laumontite pseudo-amygdaloidal outcrops, across the area of Keweenawan in Minnesota. F. F. Grout, analyst.

	1	2	3	4	5	6
SiO_2	48.68	53.20	48.27	42.35	47.22	47.54
Al_2O_3	19.29	15.83	16.29	17.24	17.17	17.40
Fe_2O_3	4.07	3.39	4.55	9.90	10.21	9.21
FeO	8.31	6.79	10.09	2.69	2.47	2.71
MgO	5.52	5.44	4.94	7.01	5.00	5.14
CaO	7.78	6.95	8.42	7.47	6.58	6.40
Na_2O	3.49	3.73	2.14	0.93	2.70	2.61
K_2O	1.16	1.34	0.77	1.48	2.15	1.80
H_2O-	0.10	0.63	0.64	1.57	0.54	0.73
H_2O+	0.16	1.44	1.67	7.13	3.73	4.38
TiO_2	1.70	1.35	2.46	1.84	1.96	1.79
CO_2	....	....	0.05	0.10	none	0.15
P_2O_5	0.05	....	0.14	0.14	0.15	0.06
S	....	....	0.04	none	none	0.04
MnO	....	0.15	0.17	0.15	0.12	0.11
BaO	....	....	0.04	0.01	0.03	0.02
Cr_2O_3	....	....	none	0.01	0.02	0.02
	100.31	100.24	100.71*	100.02	100.05	100.11
Specific gravity	....	....	2.986	2.695	2.821	2.778
	Hessose	Andose	Auvergnose	....	....	....

* CuO=0.03.

Conchoidally fracturing diabase.—This fracture appears only in the base of most flows, but throughout the whole mass in a few flows. The augite in these is less prominent and in small grains. The feldspar, also fine, is labradorite, oligoclase, or even orthoclase when recognizable. Olivine has not been recorded, but A. C. Lane concludes from the form of some secondary minerals, that they replace olivine. The composition indicates that olivine might develop, but, as in the previous types, it is best to assume its presence in some, but not all, of the rocks of this field type.

TABLE III

ANALYSES OF CONCHOIDALLY FRACTURING DIABASES

1. Type locality, Bed 65, Eagle River section, Keweenaw Point, Mich. George Steiger, analyst. *Journal of Geology*, XVI, 765.
2. Crooked Creek, Pine Co., Minn. Average material. F. F. Grout, analyst.
3. Tamarack Creek, Pine Co., Minn. Altered, but hard. F. F. Grout, analyst
4. Mouth of Kettle River. Altered to red clay. Partial analysis by F. F. Grout.

	1	2	3	4
SiO_2	50.07	53.16	65.00	43.35
Al_2O_3	12.63	15.12	14.01	20.42
Fe_2O_3	3.84	5.95	6.42	
FeO	10.30	6.75	0.44	13.57
MgO	5.23	4.76	2.83	5.17
CaO	6.55	5.74	0.85	0.27
Na_2O	3.53	2.38	1.82	0.35
K_2O	1.90	1.54	5.42	5.46
H_2O-	0.86	0.38	0.26	4.24
H_2O+	1.96	1.92	1.93	5.54
TiO_2	2.50	1.68	0.69	0.92
CO_2	none	0.05	0.07	....
P_2O_5	0.22	0.09	0.07	....
S	none	0.04	none	....
MnO	0.42	0.17	0.10	....
BaO	0.02	0.02	0.06	....
	100.03	99.75*	99.97	99.29
Specific gravity	......	2.882	2.690	....
	Camptonose	Bandose	Nameless Hispanare	....

* CuO=0.02.

Alteration giving hematite is probably responsible for the red color of many outcrops. Sections reveal the fine-grained pseudomorphs after plagioclase, in a ground-mass, usually darkened by hematite, especially where it seems probable an augite area existed.

A large part of the ground-mass is now orthoclase in one or two sections examined, but many other minerals are associated: quartz, calcite, chlorite, etc.

Porphyritic variations.—In Minnesota, phenocrysts from one-half to two inches long are developed in the conchoidal and hackly fracturing types at several localities. At Taylors Falls they are red and elsewhere usually gray. The fresh samples are labradorite, but alteration had the same effects on these large crystals that were revealed in the smaller ones. As the grain becomes dusty and granular, extinction becomes wavy, twinning bands disappear, and if there is an aggregate extinction the angle is low. A hard rock of this type can be followed along the strike for some miles on Kettle River. Two samples from widely separated points differ from each other so little that only the average is given in Table IV. The extreme was a variation from 6.05 to 6.89 per cent of lime. The phenocrysts have not affected the composition to make it differ much from non-porphyritic types.

Glasses.—A few inches at the base of each flow is commonly of the appearance of devitrified glass, and the immediate region of the amygdules at the tops of flows is similar. The alteration is advanced, though the crystallization is never very coarse. The conchoidal fracture remains, and in plain light the sections reveal microlites in a translucent field, and a few show flow structures.

Amygdaloidal textures.—Most of the flows have an upper zone, not sharply distinct from the main body, but characterized by increasing numbers of cavities, around which the rock is more glassy than elsewhere. Such porous glass, chemically unstable and physically weak, and affording good channels for water-circulation, now contains such a variety of secondary minerals that it seems hard at first sight to assign them all to the same rock for origin. Some cavities are now open—probably from recent leaching; some are filled with a single mineral; some contain three or four minerals in complex relation to each other. The series of minerals in order of formation has been generalized in the Michigan reports, and is essentially correct in this area. Table IV includes two analyses of Minnesota amygdaloids, but they are not in this particular Keweenawan area.

TABLE IV

ANALYSES OF AMYGDALOIDAL AND PORPHYRITIC ROCKS

1. Porphyritic diabase, Kettle River, east of Hinckley, Minn. Average of two samples, some miles distant. F. F. Grout, analyst.

2. Thomsonite-bearing rock, Good Harbor Bay, Lake Superior. C. F. Sidener, analyst.

3. Similar rock, decomposed, nearer Grand Marais, Lake Superior. C. F. Sidener, analyst.

	1	2	3
SiO_2	50.48	46.80	45.37
Al_2O_3	16.33	15.21	18.21
Fe_2O_3	5.99	13.13	1.22
FeO	7.10		
MgO	4.08	8.13	6.98
CaO	6.47	11.11	11.49
Na_2O	2.44	1.95	0.84
K_2O	1.39	0.01	0.02
H_2O-	0.46	....	....
H_2O+	2.70	2.79	4.66
TiO_2	2.15	....	....
CO_2	0.01	....	....
P_2O_5	0.21	....	....
S	0.01	....	....
CuO	0.02	....	....
MnO	0.16	....	....
BaO	0.04	....	....
	100.04	99.13	99.77
Specific gravity	2.886	.....	.....
	Bandose	Auvergnose	.....

Amygdules and other secondary rock minerals.—Chlorite is probably the most important mineral of this group, forming amygdules, pseudo-amygdules, and pseudomorphs after glass, olivine, augite, and even plagioclase, with prehnite as an intermediate product. The similarity of constituents of this green earth and augite suggests that much of it originated from that mineral, and this idea is confirmed by the absence of much chlorite in the rocks low in augite. The variety of occurrence, however, as well as some small variations in optical properties, indicates several methods of formation and a variable composition. An early test of composition, by McFarlane of the Canadian Geological Survey,[1] by fractional solution in nitric acid and alkali gave a solution indicating the composition of delessite.

[1] Canadian Geol. Survey, *Report of Progress*, 1863–66.

Pumpelly had an analysis made with similar results. Both samples represented pseudo-amygdules, and the results have been widely accepted, though it seems possible some other constituent may have been attacked with McFarlane's chlorite. Dr. Berkey[1] found the chlorite amygdules of Grand Marais on the north shore of Lake Superior to be strigovite. Three of the samples now tested seem to be much like delessite and the fourth does not seem to be a definite chlorite. The analyses, though similar to those given by Dana, are quite different from earlier analyses of Keweenawan material. Those

TABLE V

Analyses of Chlorite and "Green Earth"

1. Chlorite, silky amygdules, Pine City, Minn. F. F. Grout, analyst.

2. Chlorite pseudo-amygdules, Upper Tamarack Creek, Minn. F. F. Grout, analyst.

3. Green earth of slickensides, Crooked Creek, Minn. F. F. Grout, analyst.

4. Green mineral from rock analyzed, Number 3, Table IV. C. F. Sidener, analyst.

	1	2	3	4
SiO_2	31.84	31.87	44.60	39.00
Al_2O_3	18.32	17.58	6.93	8.41
Fe_2O_3	2.59	7.63	9.59	10.69
FeO	13.80	8.67	3.94	
MgO	20.64	20.81	19.98	19.64
CaO	none	trace	0.74	3.59
Na_2O	trace	none	0.61	0.29
K_2O	trace	0.92	0.15	none
H_2O-	1.80	0.47	8.00*	....
H_2O+	10.40	11.63	5.00	17.07
CO_2	0.13	....	0.13	....
TiO_2	....	0.15	0.06	....
	99.52	99.73	99.73	98.69
Specific gravity	2.739	2.777	2.500	.....

* The moisture lost on drying at 100°, though great, was almost entirely regained after exposure to ordinary air.

were low in magnesia and high in alumina and iron oxides. The high ferric oxide which has been mentioned in connection with reduction of copper is less prominent in these new analyses. The chlorite has a hardness of about 2, and the color varies—usually green and light enough so that sections are very faintly colored. The structure

[1] C. P. Berkey, Minn. Geol. and Nat. Hist. Survey, *Ann. Report 23*, 194.

is usually radial, but in some, confused and very fine grained; double refraction is very slight and still notably variable.

Probably second in importance as an alteration product in these rocks are laumontite and related minerals. Their occurrence is mentioned above and it is now time to discuss the evidence of the relation of laumontite to an aggregate of quite different composition. The laumontite crystals, occurring on Snake River in greatest abundance, are red in color and usually form radiating groups up to two inches across. Terminal faces have developed on distinct prisms up to a quarter of an inch in thickness. The termination is the common laumontite form, classed as a dome (201) by Dana. The angle from prism to this dome varied quite widely in the crystals measured, but apparently this was due to the enlarging prism in the radiating group. Several measurements, by both hand and reflection goniometers, lay very close to the correct figure 113° 30′ and the rest varied within 5 degrees below that value, with no point more prominent than the rest. A trace of the pinacoid face could be seen on a few crystals. The prismatic cleavage is prominent, especially after the mineral has stood a time in a dry warm room. The blowpipe and physical characters clearly identified it.

Thin sections indicate hematite as coloring matter rendering the section dusty, but other alteration products contributed to this effect. Extinction was often wavy, and inclusions of different orientation crossed some grains in such a way as to remind one of microperthite. Such was the material of Sample 2, Table VI.

Light-green pseudomorphs formed from this red mineral. They preserved the angles of the original and showed the same development and imperfections. In a few illustrative specimens, the red center of laumontite is visible in broken green prisms. The cleavage cracks of laumontite show as light or more transparent lines in the pseudomorph. At this type locality, the chief chemical change is the replacement of lime and some water, by potash and magnesia. No formula is yet suggested for the mineral, however, because of the variation in similar material from other localities. It has a hardness of 3; specific gravity of 2.7; fusibility of 3; soapy feel; is an aggregate of grains, none of which was over 0.01 mm. in length; is anisotropic and has medium birefringence. Hydrochloric acid dissolves very little, and

TABLE VI

ANALYSES OF LAUMONTITE AND RELATED PRODUCTS

1. Light-pink laumontite, Pine City, Minn. F. F. Grout, analyst.

2. Dark-red laumontite, Pine City, Minn. F. F. Grout, analyst.

3. Dark-red laumontite, Kettle River, Minn. F. F. Grout, analyst.

4. Lightest fraction of red pseudo-amygdaloid, Crooked Creek, Minn. This is not a clean separation from feldspar, as shown by the next sample. F. F. Grout, analyst.

5. Next to the lightest fraction of the foregoing sample, No. 4. F. F. Grout, analyst.

6. Green pseudomorph after laumontite like sample No. 2. F. F. Grout, analyst.

7. Appeared to be bleached and further altered from sample No. 6. F. F. Grout, analyst.

8. Amygdules of similar appearance, Upper Tamarack Creek, Minn. F. F. Grout, analyst.

9. Pseudo-amygdules of similar appearance, associated with chlorite and hematite, Upper Tamarack Creek, Minn. F. F. Grout, analyst.

	1	2	3	4	5	6	7	8	9
SiO_2	51.34	49.66	49.44	48.85	53.58	53.73	53.02	62.78	48.80
Al_2O_3	22.48	21.15	20.62	25.01	}	15.08	20.55	15.52	19.63
Fe_2O_3	0.55	1.32	2.86	2.19	} 26.16	4.24	1.94	2.06	} 8.87
FeO	0.15	0.21	trace	trace	}	2.36	1.36	0.20	}
MgO	0.97	1.44	1.29	1.73	1.67	9.12	7.31	3.19	7.50
CaO	10.68	9.16	9.46	6.84	5.56	0.08	0.08	none	trace
Na_2O	1.23	1.49	0.60	2.36	3.90	0.38	0.72	none	0.30
K_2O	0.40	1.38	1.66	2.21	3.16	8.02	6.20	5.82	5.98
H_2O-	1.66	2.90	2.40	2.00	....	1.02	1.82	6.23	1.74
H_2O+	10.14	10.80	11.97	9.34	....	5.55	5.36	4.50	6.30
CO_2	0.10	0.12	....	....	....	....	....	....	....
TiO_2	....	....	0.18	0.10	....	0.03	trace	0.06	0.77
	99.70	99.63	100.48	100.63	Incomplete	99.61	98.36*	100.36	99.89
Specific gravity	2.353	2.315	2.381	less than 2.580	2.581	2.750	2.677	2.581	....

* Two sets of duplicate analyses yielded consistently low summation. The alkali determination showed the poorest agreement; and the figure reported is that from the two highest results which were in close agreement. Sulphur, and carbonic acid are not present in amounts sufficient to change the total much.

yields no jelly as laumontite does. By thorough treatment with this acid and alkali, only 25 per cent is extracted and the extract resembles the original except in having more iron and none of the sodium and potassium. However, the addition of sulphuric acid, in the above treatment, makes decomposition complete. As the orthoclase of this same district gives only 3 per cent to this treatment, it seems certain

that this material is not a mixture of orthoclase and another mineral. No other mixture seems to fit the case and although the analyses show considerable variation it is quite certain that we are dealing with material not hitherto described. At least, it is a new alteration product for laumontite. It is here proposed that the new mineral be called *pseudo-laumontite*. Chemically it is unique in combining potassium and magnesium in a silicate. The rock-analysis No. 5, of Table I, resembles the analyses of pseudo-laumontite closely enough to be of interest in this connection.

TABLE VII

ANALYSES OF MISCELLANEOUS AMYGDULES

1. Orthoclase, fine-grained, salmon-pink tufts lining cavities, T.39N., R.21W., Pine City, Minn. F. F. Grout, analyst.

2. Analcite, red and white mottled crystals, associated with either laumontite or orthoclase, Pine City, Minn. F. F. Grout, analyst.

3. Prehnite, radiating groups in a light-green vein-filling, T.41N., R.20W., Kettle River, near Hinckley, Minn. F. F. Grout, analyst.

4. Datolite, enamel-like bunches, associated with chlorite in cavities, Pine City Minn. F. F. Grout, analyst.

5. Chalcedony, Crooked Creek, Pine Co., Minn. F. F. Grout, analyst.

	1	2	3	4	5
SiO_2	61.69	55.76	45.31	36.50	97.85*
Al_2O_3	19.46	23.24	20.60	trace	0.18
Fe_2O_3	0.76	0.53	5.45	3.58	0.46
FeO	0.93	0.40	trace	trace	
MgO	0.52	0.55	0.63	1.25	0.17
CaO	trace	trace	23.66	33.28	0.30
Na_2O	0.20	11.79	0.31	none	p.n.d.
K_2O	15.00	0.07	0.19	0.10	p.n.d.
H_2O-	0.10	0.10	0.16	0.16	none
H_2O+	0.97	8.06	4.40	5.95	1.00
CO_2	0.15	0.15	....	0.20	none
TiO_2	0.10	trace	....	0.10	0.04
B_2O_3	....	....	....	18.88*	....
	99.88	100.65	100.71	100.00*	100.00*
Specific gravity	2.615	2.283	2.896	2.951	2.618

* The percentage of silica in chalcedony and of boric acid in datolite are found "by difference." The difficult method of estimating boric acid gave the analyst 17.36 per cent B_2O_3 instead of 18.88. Material was exhausted before it was satisfactorily checked.

Several other minerals have been tested, chiefly by analysis, to estimate their purity. Analcite yielded measurable crystals of the common form. All of the mineral occurrences recorded with the

analyses are new occurrences. As datolite is new to the state except in the drift, it is worthy of record that it has another occurrence, on Crooked Creek. Record of metallic copper from many points might be made, but the mineral needs no analysis, except for silver, which was not found.

THE CHEMICAL CLASSIFICATION.[1]—Grouping the twelve new analyses of rocks that show little alteration (less than 3 per cent combined water) with five earlier results which seem to be good, the chemical character of the diabases may be summarized. More results fall in the subrang *Hessose*, than any other, and this is a persodic, docalcic, perfelic dosalane. The similar groups Bandose

TABLE VIII

ANALYSES OF BASIC DIABASE DIKES OF MINNESOTA

1. Diabase dike, Stearns Co., Minn. B. F. Noehl, student analyst.
2. Olivine diabase dike, Carlton Co., Minn. W. H. Truesdell, student analyst.
3. Diabase dike, Stearns Co., Minn. Average of two analyses, side and center of 14-foot dike, essentially the same. F. F. Grout, analyst.
4. Diabase with phenocrysts of quartz and feldspar in a 5-foot dike. F. F. Grout, analyst.

	1	2	3	4
SiO_2	50.51	49.34	48.45	52.91
Al_2O_3	15.30	13.03	12.70	17.56
Fe_2O_3	1.79	2.50	2.00	0.00
FeO	8.14	13.74	13.24	8.61
MgO	5.94	3.64	4.39	4.90
CaO	9.04	7.40	8.50	7.55
Na_2O	5.18	4.55	3.94	3.72
K_2O	2.00	1.57	1.22	1.70
H_2O-	0.00	0.24	0.00	0.00
H_2O+	1.43	0.69	1.58	1.57
CO_2	....	0.96−	0.00	....
TiO_2	2.80	3.16	3.17	0.92
ZrO_2	....	0.04	....	....
P_2O_5	....	0.15	0.72	0.20
MnO	0.51	0.51	0.17	0.11
S	....	0.12	....	....
BaO	....	0.03	....	....
Cr_2O_3	....	0.02	0.10	0.20
	102.64	101.64	100.18	99.95
Specific gravity	....	....	2.90	2.840
	Limburgose	Kilauose	Auvergnose	Hessose

[1] *Journal of Geology*, X, 555.

and Auvergnose are well represented. Of the 17 analyses, 17 are persodic, 12 are docalcic, 12 are perfelic, 10 are dosalic. The variation of the others is not uniform.

Such relationships in composition may be taken as evidence of origin from a common magma, and the differences that exist in the unaltered rocks are therefore to be attributed to some process of differentiation. Alteration is too great for accurate discussion of the subject. Mr. Lane has raised the question of differentiation in a single flow.[1] His opportunity to examine extensive drill cores, gave him results that are beyond comparison with any now to be added from a rapid field survey. He found some changes which appeared to be due to an early separation of oligoclase which was lighter than the basic magma, and rose, affecting both composition and texture. Analyses are offered in confirmation, but the high degree of alteration, indicated by 5 per cent water and 1 per cent carbonic acid, makes the chemical evidence of much less value than the microscopic work. Mr. Lane does not suggest that such action was common in the

TABLE IX

Analyses of Basic Laccoliths of Minnesota

1. Gabbro, Richmond, Minn. E. M. Pennock, analyst.
2. Gabbro, Little Falls, Minn. Miss Lillian Nye, student analyst.
3. Gabbro, Duluth, Minn. Several student analysts obtained results, from 102 to 103 per cent. The lowest is by G. H. Stone, given below.

	1	2	3
SiO_2	52.34	44.16	49.42
Al_2O_3	14.17	14.89	24.47
Fe_2O_3	2.40	1.19	3.13
FeO	10.78	6.83	6.13
MgO	3.51	14.40	1.00
CaO	7.25−	13.01	8.45
Na_2O	3.73	1.92	4.98
K_2O	2.37	0.97	1.15
H_2O-	0.18	0.05	0.06
H_2O+	0.43	0.89	0.55
TiO_2	2.21	0.89	1.87
P_2O_5	0.80−	....	0.04
MnO	0.09	trace	0.11
S	0.14+	....	0.11
	100.40	99.30	101.48
	Camptonose	Portugare	Andose

[1] A. C. Lane, *Michigan Geol. Survey*, VI, 215.

Keweenawan, and no such case has been noted in Minnesota. Slight peculiarities were not rare; as, for example, the gneissic appearance, mentioned by Professor Hall regarding a Pine City exposure. This was prominent in the lower twenty-five feet of a thick hackly flow.[1]

In Michigan some diabase dikes in rocks near the lavas have been compared with the lavas, as an indication of their relationship. A similar comparison may be instituted here for Minnesota, and extended to include other occurrences of basic rocks in the central and northeastern part of the state. Earlier analyses reported by Streng, Winchell, and Irving are included in the tabular comparison, but analyses are not quoted.

TABLE X

CHEMICAL CLASSIFICATION BY LOCALITY AND FORM

	Labradorose	Dacose	Varingase	Tonalose	Bandose	Shoshonose	Andose	Hessose	Vaalose	Kilauose	Camptonose	Ornose	Auvergnose	Limburgose	Dosodic Docalcic Portugare
Minnesota flows.......	−	−	+	+	+	−	+	+	−	−	+	−	+	−	−
Michigan flows........	−	−	−	+	+	−	+	+	−	−	+	+	+	−	−
Minnesota dikes.......	−	−	−	−	−	+	−	+	−	+	−	−	+	+	−
Michigan dikes........	−	−	−	−	−	−	−	+	+	−	−	−	+	−	−
Duluth gabbro........	+	−	−	−	−	−	+	+	−	−	−	−	−	−	−
Stearns Co. gabbro....	−	+	−	−	−	−	+	+	−	−	+	−	+	−	±

TABLE XI

TYPES OF DIABASE CHEMICALLY CLASSIFIED

	Hispanare	Tonalose	Bandose	Shoshonose	Andose	Hessose	Kilauose	Camptonose	Auvergnose
Mottled type	−	−	−	−	−	+	−	−	−
Hackly type......	−	+	+	−	+	+	−	+	+
Conchoidal type ..	+	−	+	−	−	−	−	−	−
Dike rock........	−	−	−	+	−	+	+	−	+

[1] C. W. Hall, *Bull. Geol. Soc. Am.*, XII, 313.

DIABASE AND GRANOPHYRE OF THE GOWGANDA LAKE DISTRICT, ONTARIO

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INTRODUCTION

The rich silver deposits of Nipissing and Temiskaming districts of Ontario are believed to be genetically connected with intrusive diabases. Chiefly on this account, these diabases have received considerable attention from many Canadian geologists.

During the summer of 1909 special opportunity for studying these rocks was afforded by the Ontario Bureau of Mines, to the writer, while working in the vicinity of Gowganda Lake.

The results of this study form the basis of this paper.

GENERAL GEOLOGIC RELATIONS

A brief résumé of the geologic history of the Gowganda district[1] will be given in order that general relationships may be well understood.

The oldest rocks consist of a complex of chloritic and hornblendic schists (altered basic volcanics), cut by quartz porphyries; together with a minor quantity of jasper-iron formation and its associated schists. This schist series (Keewatin) was subjected to intense folding and its schistose character induced before the intrusion of the great granite batholiths which in numerous places in the area are seen cutting the series. This complex (Archaean) suffered a long period of erosion before the deposition of the sedimentary series now lying upon it. The lower series is made up of conglomerates, quartzites, and slates of varying thickness. This in turn suffered erosion, but apparently little disturbance, before the deposition of the conglomerate-arkose-quartzite series lying upon it. These series have been called Lower and Middle Huronian respectively. Into

[1] See also forthcoming report and map by A. G. Burrows, Ontario Bureau of Mines, 1910.

all the foregoing series are intruded sills and dikes of diabase, the sill-like form being generally assumed in the sedimentaries. The succession here noted is essentially that found in all the Huronian areas of northern Ontario which have received careful study. The diabase is of remarkably uniform character in widely separated districts.

Throughout the Gowganda area, with few local exceptions, the sedimentaries with their sills have been little disturbed. They lie in monoclinal blocks with average dips of about 12 degrees to the east.

NORMAL SILL DIABASE

The normal diabase of the sills is, when unaltered, a dark-gray, medium-grained, holocrystalline rock, of which the chief constituents are plagioclase and pyroxene with a very little quartz, micropegmatite, biotite, apatite, and black iron ore.

The plagioclase, amounting to about 60 per cent of the total, occurs in stout laths with average length of about 0.5 mm., idiomorphic against pyroxene. Extinction angles place it as medium labradorite, $Ab_{35}An_{65}$. Sometimes zonal growth is shown and in favorable cases the outer zone could be determined as acid labradorite, $Ab_{45}An_{55}$. The plagioclase is generally somewhat altered, minute scales of white mica being the chief product of alteration. The pyroxene is in irregular grains between the feldspar laths. There appear to be two varieties. Normal augite with the usual high interference colors, high extinction angle, and frequent twinning is the more common. The average size of individuals is about 0.5 mm. In lesser amount occur grains of average diameter 2.0 mm. without twinning, showing nearly always parallel extinction, but in some sections as high as 10 degrees inclination. The maximum interference color is a pale yellow of the first order; the optical character is positive as in the augite; a faint pleochroism is shown. Bayley describes a mineral in his Pigeon Point rocks[1] which seems to be identical. The relation of this pyroxene to the feldspar is the same as that of the augite, but the large size of its grains suggests that it *began* to crystallize sooner. The pyroxene is probably enstatite. The appearance of slightly oblique extinction in rare cases is to be explained in its

[1] *Bull. 109*, U.S.G.S., 36, 45.

wide axial angle. The slide presents no difference whatever from the diabase of the Cobalt area. Biotite, black iron ores, and apatite are the accessory minerals. Small areas of micropegmatite of quartz and an indeterminate feldspar are always present.

GABBRO

In places the diabase has moderately coarse phases with augite in stout prisms showing one perfect cleavage face, the diallagic parting, which determines the fracturing of the rock. The cleavage face is nearly always bent, sometimes into a considerable arc. This bending is a constant character of the augite of the coarse phase from widely separated points. Under the microscope this phase shows a nearly simultaneous crystallization of augite and plagioclase, the feldspar in broad areas generally inclosing the augite.

The feldspar is an acid labradorite, $Ab_{45}An_{55}$, approximately that of the outer zones of the crystals of the normal diabase. Some zonal growth was shown in a few examples, the outer zones being slightly more acid.

The pyroxene is augite throughout, with cleavage parallel to 100 and a lamellar structure parallel to the base. Enstatite is absent. The augite has often gone over, partly, to uralite. Both augite and plagioclase are in stout prisms of about 3 mm. average length. There is no evidence of granulation of any of the constituents, so the bending of the augite must be attributed to disturbance during crystallization. A little iron ore occurs, and moderately coarse micropegmatite interstices in small amount. The feldspar of these could not be determined. Where micropegmatite is in contact with iron ore and augite, secondary biotite has sometimes been built. The rock is a gabbro, near augite diorite.

No definite relation of the gabbro to the sill boundaries could be made out. There is usually a gradual passage from diabase to gabbro, but in some cases small dikelike masses of the gabbro were found in diabase. The gabbro probably represents the more slowly crystallized, slightly more acid parts of the sills. This phase is well developed in the area west of Logan Lake. In places in this area the gabbro becomes very coarse, with pyroxenes up to three inches in

length, often showing alignment, indicating motion in the mass during crystallization.

TABLE I

SiO_2	50.12				
Al_2O_3	15.70				
Fe_2O_3	1.42	Norm.			
FeO	6.89	Or	6.12	F=54.82.	Sal.=56.24
MgO	9.50	Ab	22.01		
		An	26.69		
CaO	11.30	Nep	1.42	L= 1.42	Fem.=43.34
Na_2O	2.91	Di	23.73	P=23.73	
K_2O	1.07	Ol	16.22	O=16.22	
H_2O+	1.03	Mt	2.09	M	
		Il	1.06		
H_2O-	0.21	Pyr	0.24	A	
TiO_2	0.55	III, 5, 4, 3			
S	0.14	Auvergnose			
	100.84				

I. Normal Diabase, O'Brien Mine, Cobalt. N. L. Bowen, Analyst

DIKES

In the Davidson Lake sill, which will be described later at greater length, a well-defined dike of fine-grained diabase was found cutting the normal sill rock. Slender laths of plagioclase averaging 0.3 mm. in length are set in a matrix of augite. The plagioclase is very fresh and ranges from acid labradorite to acid bytownite. Augite fills the interspaces and is sometimes altered to a felt of needles of low birefringence with skeletons of iron ore, like the alteration products described by Pirsson in West Rock diabase.[1] Iron ore forms about 15 per cent of the rock. There is a little pyrite, but at least some of this has filtered in along tiny seams. No quartz could be found.

Dikes are exceedingly numerous in the Archaean, often up to 250 feet in width and of very uniform character. With the exception of the chilled margin the dikes are in most cases composed entirely of dark-gray, rather fine-grained, normal diabase. Sometimes, however, large phenocrysts of feldspar up to 2 inches in length, often with a flow arrangement parallel to the walls, stand out on the weathered

[1] Diller, *Educational Series of Rock Specimens*, 271–72.

surfaces. One especially fine example lies east of Davidson Lake where a dike about 200 feet wide, cutting the Archaean complex, shows phenocrysts from wall to wall. Only one dike, definitely determinable as such, was seen in the sedimentaries and this was near the basement Archaean. This was of the porphyritic type. The phenocrysts carefully determined in oriented sections are mainly a uniform andesine, $Ab_{55}An_{45}$. A narrow outer rim usually shows zonal growth with zones of labradorite, $Ab_{45}An_{55}$, and andesine alternating. In some cases the phenocrysts contain idiomorphic crystals of olivine near their outer edges.

The ground-mass consists of plagioclase, augite, olivine, apatite, and iron ores.

The plagioclase is mainly labradorite sometimes showing zonal growth, with acid andesine forming the outer zones. In a few cases the core is andesine with a zone of labradorite surrounding it and then again andesine as the outer layer.

The olivine is in small grains, usually very fresh. It is optically negative and therefore belongs to the iron-rich olivines. Most of it appears to have crystallized before the feldspar of the ground-mass. A brownish augite fills interspaces of the ground-mass between the feldspar laths in perfect ophitic structure. Apatite is unusually abundant, in very long needles, which penetrate all the constituents. No quartz or micropegmatite were found. Black iron ores are rather abundant.

GRANOPHYRE AND RELATED ROCKS

None of the dikes show evidence of differentiation as far as can be determined in the hand specimen. The sills, however, are not always entirely composed of the dark-gray diabase. In places we often see little pink spots, found to be areas of micropegmatite (quartz and albite). This material may increase in amount until it forms quite the whole of the rock, giving rise to "red rocks" or granophyres. Moreover pink aplitic veins are often numerous in the sills. To the development of these "red rocks" and their relations to the diabase and inclosing sediments attention will now be given.

DAVIDSON LAKE SILL

Close to the west shore of Davidson Lake is a sill about 50 feet thick cutting the arkoses of the Middle Huronian (Fig. 1).

Its western edge (the base) has a chilled margin against the sediments. The arkose has been bleached; otherwise there is no notable effect at the contact. As we approach the eastern edge (the top) we find "pink spots" appearing in the diabase. The actual contact could nowhere be found, but at one point the sill rock within a foot of the sediment was seen to consist entirely of a pink feldspathic

FIG. 1.—Ideal section at Davidson Lake. ark. = arkose; di. = diabase; gr. = Archaean granite.

variety. The microscope shows this rock to be made up of phenocrysts of acid plagioclase (albite to oligoclase-albite) in a groundmass of the same material with quartz and a small amount of augite and black iron oxide.

THE FOOT LAKE SILL

To the northwest of Foot Lake, diabase is found in contact with a narrow band of Lower Huronian slates (*A*, Fig. 2).

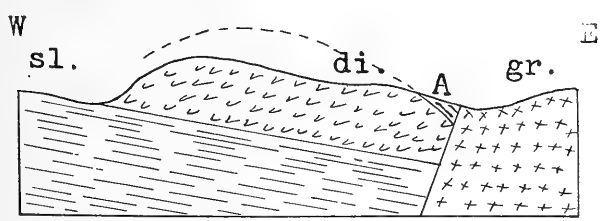

FIG. 2.—Ideal section of Foot Lake sill (laccolith). sl. = slate; di. = diabase; gr. = granite.

The slates near the contact normally greenish to pale reddish are changed in color to a deep purplish red. Under the microscope it is found that each lamina of sediment has been transformed to a mosaic of quartz and feldspar with a considerable proportion of chlorite and small grains of black and red iron ore. In the varying proportion of

chlorite and the varying "grain" of the mosaic the original lamination of the sediment is preserved. The feldspar is stained a deep red by tiny flakes of hematite. In a few individual grains albite twinning was discernible and the extinctions combined with the indices determined them as albite. Rarely small garnets are found.

It is typical adinole of diabase contacts believed to be produced by waters emanating from the diabase.

The intrusive becomes finer in grain as it approaches the sediment. For about three inches from the contact the diabase has a few "red spots" and these prove to be micrographic intergrowth of quartz and albite. The red color is seen to be due to little flakes of hematite in the feldspar. The plagioclase of the diabase proper has in large part gone over to sericite, and most of the augite to chlorite. Small pink garnets are an important constituent of this micropegmatite and sometimes amount to about 10 per cent of its bulk.

In places a zone of brecciated slate a few inches wide occurs along the contact. The "diabase" filling the spaces between fragments of slate is very rich in this pink micropegmatite (quartz and albite); is indeed sometimes composed almost entirely of it. Obviously the altered sediment has been influential in the production of this granophyric material (see Fig. 5).

About 100 yards south of the point just described, and on the same contact, the diabase has again these "red spots" near its contact and it passes rather abruptly into a reddish feldspathic rock about 5 feet thick. This is found under the microscope to consist of large phenocrystic individuals of albite in a ground-mass of quartz, albite, and chlorite. The quartz amounts to about 15 per cent and the chlorite to about 30 per cent, black iron ore about 5 per cent. A very few small garnets are scattered throughout the rock. The albite has again the tiny flakes of hematite, whence the red color. Small areas of very fine micropegmatite are found, showing the beginning of a granophyre structure. The rock has obviously the composition of adinole and passes quite gradually into the reddish-purple adinole which retains the structure of the original sediment. It is merely the more perfectly recrystallized adinole, closer to the intrusive. The granophyric material of special development in the diabase close to its contact has been introduced from the adinole at the time of its forma-

tion by some sort of "transfusion."[1] It has the same composition (albite and quartz, with some chlorite and garnets) as the adinole. In the diabase near this contact aplitic veins, consisting essentially of albite and quartz, are especially numerous.

LILY LAKE SILL

The diabase to the southwest of Lily Lake has often a high proportion of "red spots." On the north boundary of H.S. 646,[2] (*A*, Fig. 3) is found a variety which in the hand specimen would be termed a syenite. It is, in fact, composed almost entirely of the granophyric material which forms the "red spots." Under the microscope it shows phenocrysts of albite in a graphic intergrowth of quartz and feldspar, with a tendency to radial arrangement about the phenocrysts. The feldspar of the graphic growth is often in con-

FIG. 3.—Ideal section at Lily Lake. sl. = slate; di. = diabase

tinuous orientation with the phenocrysts. Sometimes the albite twinning lamellae pass from the phenocrysts into the feldspar of the micropegmatite without interruption. A very small proportion of the feldspar of the graphic material is a microperthite. Chlorite, apatite, iron ore, and calcite are present in small amount. The rock is a typical granophyre.

There is a small patch of thinly laminated graywacke slate within thirty feet of the outcrop of this granophyre. It evidently overlies the granophyre, but the two could not be found in contact. Some of the slate is altered by the intrusive into a rock with alternating dark greenish chloritic and reddish feldspathic laminae. Other parts of the slate are less altered and some apparently unaltered. Some chemical determinations made in samples of the altered slate will be given later.

[1] A. Harker, *Natural History of the Igneous Rocks* (1909), 304.

[2] See map by A. G. Burrows, Ontario Bureau of Mines, 1910.

THE LOST LAKE SILL

The best exposure of granophyre found lies along the west shore of Lost Lake (Fig. 4). In the hand specimen it would be termed a hornblende syenite. It lies at the top of a diabase sill which diamond drilling has shown to have a thickness of more than 500 feet, probably much more. Here a vertical thickness of about 30 feet of granophyre is exposed on the hillside overlooking the lake. Capping the hill is a thin veneer of nearly flat-lying sediments. It is difficult to draw an exact line of contact. Between what is unquestionably altered sediment, and granophyre is a layer about 1 foot thick of a purely feldspathic rock, red in color, and very similar to the granophyre. The microscope shows only feldspar (albite), with a little calcite and blotches of chlorite. The altered sediment close to this feldspathic

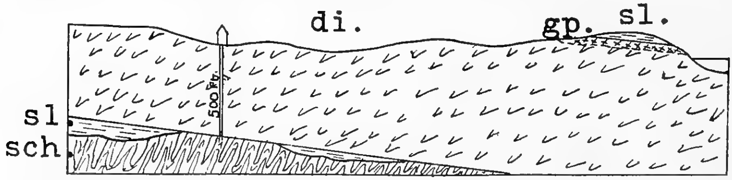

FIG. 4.—Ideal section at Lost Lake. sch. = Keewatin greenstone; sl. = slate; di. = diabase; gp. = granophyre.

layer has the granular appearance of a fine-grained indurated red arkose and under the microscope shows a mosaic of quartz and feldspar, some of which is determinable as albite. This gradually assumes a deep purplish-red color and in places passes into apparently unaltered slates. The whole change takes place within a distance of about twenty feet.

Going northward from the exposure just described there is a rather quick passage from granophyre, through diabase rich in granophyric material, to normal diabase, which is itself found in contact with little-altered slates. The granophyre is, then, not everywhere present at the upper contact of this sill, but for some reason is localized.

The granophyre itself is very similar to the Lily Lake rock. Albite phenocrysts are a little less abundant. A small part of the feldspar of the micropegmatite is microcline with, as before, some microperthite. The chlorite occurs in long blades probably secondary after hornblende. Calcite, apatite, and iron ores are again present.

TABLE II

	I	II	III	IV	V
SiO_2	62.54°	52.54	48.41	50.12	78.28
Al_2O_3	14.79	15.14	19.29	15.70	12.00
Fe_2O_3	....	0.85	1.33	1.42	....
FeO	8.49	10.73	8.27	6.89	1.19
MgO	2.08	5.22	4.70	9.50	0.37
CaO	1.49	6.92	4.93	11.30	0.29
Na_2O	6.27	5.46	5.92	2.91	6.89
K_2O	1.12	1.43	0.41	1.07	trace
H_2O	3.51	1.76	3.99	1.24	0.61
CO_2		....	2.41	....	....
TiO_2	....	1.00	0.88	0.55	0.34
	100.29	101.05	100.54	....	99.97

I. Lost Lake granophyre. Marked °, determined by N. L. Bowen, others by N. L. Turner.

II. Granophyric diabase, Pense Township. Analyst, N. L. Bowen.

III. Granophyric diabase, Bartlett property, Gowganda. Analyst, N. L. Bowen.

IV. Normal diabase, O'Brien mine, Cobalt. Analyst, N. L. Bowen.

V. Aplite vein in diabase, James Township. Analyst, N. L. Bowen.

TABLE III

	I	II	III	IV	V
SiO_2	....	62.54	60.70	75.43	79.43
Na_2O	5.12	6.27	9.33	5.72	4.73
K_2O	0.95	1.12	0.43	0.21	0.32

I. Lily Lake granophyre. Analyst, N. L. Bowen.

II. Lost Lake granophyre. Analyst, N. L. Bowen.

III. Albite rich layer at contact, Lost Lake. Analyst, N. L. Turner.

IV. Altered sediment near contact, Lost Lake. Analyst, N. L. Bowen.

V. Altered sediment near contact, Lost Lake. Analyst, N. L. Turner.

ORIGIN OF GRANOPHYRE

Summing up the evidence of the upper contacts of the sills, just described, we have at the Foot Lake sill, in one place, the special development of granophyric material in the diabase quite close to its contact with altered slate or adinole, the granophyre interstices having practically the same composition as the adinole and evidently derived from the latter by some process of transfusion. A little farther south where the action has been more intense we have a wider zone of adinole developed. Part of the adinole close to the diabase

has been to some extent recrystallized, giving the beginning of granophyric structure. The writer believes that in the case of the Lily Lake and Lost Lake sills the evidence points to a still more complete recrystallization of *part* of the adinole with the production of typical granophyre. In other words, some of the adinole was essentially in a state of aqueous fusion and crystallized as granophyre. The melt thus formed was, to a certain extent, free to diffuse into the diabase magma and gave rise to the abundant granophyric interstices near the granophyre.

If we inquire into the conditions of the formation of adinole from slates, we will find that wholesale introduction of albite, as such, is not necessary. Some magnesia, iron, and alumina are lost by the sediment. Silica has probably not been introduced, for the loss of the above-mentioned constituents suffices to increase the silica to the percentage in adinole. Finally potash, too, is lost and at the same time is replaced by soda.[1] Carbonate waters bearing a little soda could accomplish the work necessary. That such waters exist in basaltic magmas and have important effects during the late stages of crystallization is the conclusion of Bailey and Grabham in a late article.[2] If the conclusions of the present writer are correct, such waters, emanating from the diabase, have produced the adinole and the albite-rich granophyre here described. The waters supplied most of the soda and the sediment supplied alumina and silica. Calcite is an almost universal constituent of the aplite veins associated with the granophyres. It has in some cases apparently crystallized together with the aplite minerals.[3] This certainly points to the presence of carbonate waters.

It has been pointed out that magnesia, iron, alumina, and potash are the chief constituents carried away in the production of adinole. Presumably the waters carrying these would lose their solvent power at no great distance, due to fall in temperature, and they would be deposited. The small patch of altered slate at a little distance from the Lily Lake granophyre (see p. 665) may have been thus affected. The microscope shows that the most altered parts are rich in chlorite

[1] E. Kayser, *Zeit. der Deutsch. geol. Gesell.*, XXII (1870), 103 ff.

[2] *Geol. Mag.*, VI (1909), 256.

[3] A. E. Barlow, *Jour. Can. Min. Inst.*, XI (1908), 272.

(magnesia, iron, alumina, silicate) and analysis shows that the most altered parts are also richer in potash.

	Much Altered	Less Altered	Apparently Unaltered
SiO_2	54.77	58.48	61.54
CaO	0.65	1.08	0.84
Na_2O	4.85	4.81	4.73
K_2O	3.50	3.11	2.64

There is of course no check on original variation in the composition of the sediment, but the results accord so well with what would be expected, if the granophyre was formed as here imagined, that they are to be regarded as, in some degree, corroborative.

The partial analyses, Nos. IV and V, Table III, of the altered sediment (adinole) near the Lost Lake granophyre, together with its microscopic examination, show it to be an albite-quartz rock approximating the granophyre in composition. The nearly pure albite layer, No. III, Table III, between granophyre (recrystallized adinole) and adinole probably separated from the fluid granophyre. Albite is certainly in excess in the granophyre (note phenocrysts) and its separation toward the adinole would be especially favored by the composition of the latter.

That the granophyre "solution," formed as here imagined, was foreign to the diabase magma is indicated by the intense alteration of the constituents of the diabase near the granophyric interstices.[1]

The aplitic veins[2] (quartz and albite, often with calcite) which cut both granophyre and diabase were formed from the more aqueous residuum of the granophyre. They are especially numerous near a mass of granophyre. The extreme purity of their albite (note analysis No. V, Table II) points to their aqueous origin, as does also their calcite content. This aqueous residuum probably deposited also the valuable metallic content of the aplite veins and of the associated calcite veins. The association of gold with the similar soda-rich rocks of Alaska, California, and Ireland is worthy of note (see p. 671, below).

[1] See A. E. Barlow, *Jour. Can. Min. Inst.*, XI (1908), 271.

[2] N. L. Bowen, *Jour. Can. Min. Inst.*, XII (1909), 95–106.

The extent to which the comparatively simple relations, exhibited at the contacts described, would be obscured by reintrusion of the mixed magma to a higher level may well be imagined.

DISCUSSION

As opposed to the explanation of the origin of the granophyre here advanced, the explanation which would probably first suggest itself is that diabase and granophyre are normal differentiates from a common magma, influenced by gravity. This assumption would neglect the evidence of the Foot Lake contact. Here highly granophyric diabase has developed between the slate fragments of the contact breccia.

Some of the dikes which feed the sills have a width greater than 200 feet. Assuming a normal differentiation in the sills, it seems likely that it would take place in dikes so wide, giving enrichment in granophyric material toward the central portions. Evidence of this could nowhere be found.

The Foot Lake sill has a thickness of only 50 feet, yet it has the acid rock developed at its upper contact.

The theory here advanced also accounts logically for the passage of granophyre into adinole of approximately its own composition.

It has been stated that the diabase in all parts of the sills shows micropegmatite interstices. Possibly much of this material may have an origin entirely different from that of the red interstices close to the granophyre. It should, however, be remembered that the dikes are sometimes without micropegmatite.

The separation, which is here postulated, of soda-bearing carbonate waters from the magma is of course a sort of differentiation, but is not in itself sufficient to produce granophyre but only to contribute to its formation by inducing alteration of the *slaty* sediments.[1] A necessary conclusion seems to be that granophyre would not have been formed had the country rock of these intrusions been pure limestone or pure quartzite just as adinole is not produced in such cases.[2]

This conclusion suggests a test of the hypothesis here advanced in

[1] The importance of contact metamorphism in the genesis of igneous rock types has long been advocated by the French school of petrologists.—A. Michel-Levy, *Bull. Soc. Geol. Fr.*, 24 (1896), 123 ff.; also 25 (1897), 367.

[2] W. Hutchings, *Geol. Mag.*, II (1895), 122–63.

examining the association of albite-rich igneous rocks described in the literature.

In California[1] the soda-syenite famous for its association with the Mother Lode gold deposits occurs along the contact of basic igneous rocks with Mariposa slates. This syenite is in places an almost pure albite rock; at others it contains some quartz and muscovite.

In Alaska the Treadwell soda syenite[2] of the Treadwell mine cuts slate and is followed by gabbro.

In Ireland, at Croghan Kinshela, albite granite here associated with normal potash granite cuts Silurian slates.[3]

In the Isle of Man albite-rich dikes associated with diabase cut Silurian slates.[4]

The albite-rich keratophyres of Westphalia cut slates.[5]

Quartz keratophyres in Australia are associated with diorites and cut slates.[6]

A notable point concerning all of these is their small quantitative importance.

If we extend our search to rocks rich in plagioclase near albite, we find the same general association.

In the Marysville district of Montana a rock made up of quartz 40 per cent, oligoclase-albite 40 per cent, magnetite 10 per cent, muscovite 10 per cent, has been produced at the contact between gabbro and altered argillaceous sediment by a process of "hydrothermal alteration along the contact plane."[7]

Plumasite, an oligoclase-corundum rock, occurs in California as a dike cutting peridotites which in turn cut clay slates.[8] It has been considered genetically related to the albite syenites. The excess of alumina (corundum) in the plumasite is suggestive in relation to its genesis by interaction of the basic magma and clay slates.

[1] H. W. Turner and F. L. Ransome, *Folios 41, 43*, and *63*, U.S.G.S.

[2] G. F. Becker, *18th Ann. Rept.*, U.S.G.S., Part III (1896), 39 and 65; C. W. Wright, *Bull. 287*, U.S.G.S., 95.

[3] S. Haughton, *Q.J.G.S.* (1856), 268; W. J. Sollas, *Tr. R. Ir. Ac.*, XXIX (1891), 427.

[4] B. Hobson, *Q.J.G.S.* (1891), 432.

[5] O. Mugge, *L.J.* (1893), B.B. VIII, 535.

[6] A. Howitt, *Geol. Survey Victoria*, IV (1877), 75–117.

[7] Barrel, *P.P. 57*, U.S.G.S., 48.

[8] A. C. Lawson, *Bull. Univ. of Cal.*, III, No. 8, p. 219.

At very many places in the British Isles granophyres associated with gabbro occur. Rosenbusch notes this general association.[1] At many of these places the granophyre is especially rich in plagioclase near albite and together with the gabbro is intruded into *slaty* sediments. The Carrock Fell[2] granophyre and the Buttermere and Ennerdale granophyre are perhaps the best-described examples. In the latter case it has been demonstrated that the associated Mecklin Wood dolerite has reacted with the sedimentaries.[3]

Near St. David's Head, Wales, *gabbroidal* sills cut Arenig *shales*. An oligoclase-rich rock has been produced near the contact by interaction with the sediment.[4] Granophyric interstices have also been produced near the sediment even where the contact-chilling effect is noticeable. It seems impossible to deny the influence of the sediment in the production of these granophyric interstices.

It would, of course, be quite unsafe to assume that the hydrothermal action here postulated was the dominant control in the development of the British granophyres mentioned. Some granophyres (micropegmatites) are believed by certain authors to have been produced by direct assimilation of sediments.[5] The result has been in these cases essentially a normal potash-rich granite. As pointed out before, assimilation of sediment has been noted in the case of some of the British rocks described, and this introduces new complications. It is rather their general tendency to richness in soda which indicates that hydrothermal action on the sediments may have had a part in their formation.

If albite-rich rocks were normal differentiates from a certain class of gabbroidal magma, they ought to be found in any association. The kind of "country rock" should make no difference. A search of the literature, summarized in the foregoing, seems to indicate that the kind of "country rock" does make a difference. It may be that argillaceous sediments are especially susceptible to the sodic waters;

1 *Mik. Phys.*, II, 413.

2 A. Harker, *Q.J.G.S.* (1895), 125; *ibid.* (1896), 320.

3 R. H. Rastall, *Q.J.G.S.* (1906), 268.

4 J. V. Elsden, *Q.J.G.S.* (1908), 275–76.

5 W. S. Bayley, *Bull. 109*, U.S.G.S.; R. A. Daly, "Secondary Origin of Certain Granites," *A. J. Sc.* (4); A. P. Coleman, "The Sudbury Laccolithic Sheet," *J.G.*, XV, 773.

and this seems likely. Perhaps, also, water originally contained in the sediment and, in this class, in large amount, takes an important part in the transfer of material.

SUMMARY

1. The diabase of the Gowganda area occurs as sills and dikes cutting the older formations.

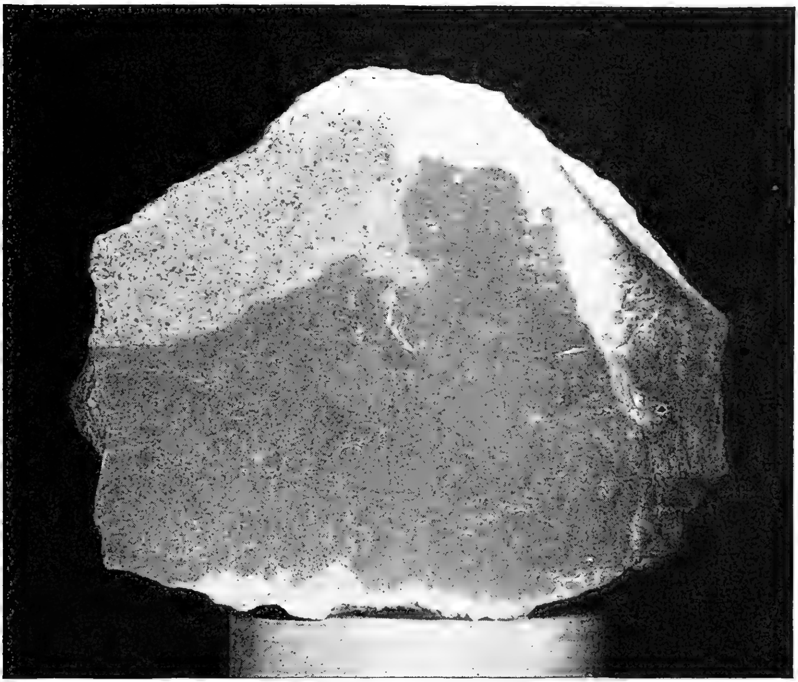

FIG. 5.—Photograph of polished specimen (natural size), showing light-colored granophyre-rich "diabase" against dark-colored, brecciated slate (Foot Lake).

2. The dike rocks are commonly porphyritic and olivine-bearing and never show distinct evidence of differentiation.

3. The sill rocks are never porphyritic; olivine is represented by the more silicic enstatite; granophyric interstices visible in the hand specimen as "red spots" sometimes occur.

4. A typical granophyre sometimes occurs at the upper contact.

5. The granophyre, like the granophyric interstices, is albite

rich and is transitional into albite-rich adinole, a product of contact metamorphism of slates.

6. The writer believes that the granophyre was, with the adinole, formed by hydrothermal action at the contact; it is an adinole which has crystallized from a state of aqueous fusion and hence with all the textures of an igneous rock.

7. The literature of albite-rich igneous rocks shows their general association with gabbros, intrusive into argillites, and leads the writer to believe that a somewhat similar action may be of rather common occurrence.

In conclusion the writer desires to thank the Ontario Bureau of Mines for those chemical determinations of this paper which were made by Mr. N. L. Turner, provincial assayer.

Editorial

The Northern Mewuk say: "In the beginning the world was rock. Every year the rains came and fell on the rock and washed off a little; this made earth. By and by plants grew on the earth and their leaves fell and made more earth. Then pine trees grew and their needles and cones fell every year and with the other leaves and bark made more earth and covered more of the rock.

"If you look close at the ground in the woods you will see how the top is leaves and bark and pine needles and cones, and how a little below the top these are matted together, and a little deeper are rotting and breaking up into earth. This is the way the world grew—and is growing still."

This fragment of dynamic geology is taken from C. Hart Merriam's *The Dawn of the World*, a book recording the lore, chiefly mythic, of the Mewan Indians of California. The Northern Mewuk live on the western slope of the Sierra Nevada, a region well calculated to exhibit the relations of regolith and soil to bed rock and to vegetation.

G. K. G.

Reviews

The Geology and Ore Deposits of Goldfield, Nevada. By Frederick Leslie Ransome, assisted in the field by W. H. Emmons and G. H. Garrey. U.S. Geol. Surv. Professional Paper 66.

Aside from the importance of a careful and thorough description of a region so rich in mineral deposits as that of Goldfield, the present volume is especially interesting to students of economic geology in that it describes a practically new type of wall-rock alteration. Hitherto the primary deposition of deposits of gold, silver, and copper have been generally ascribed to the agency of hot ascending alkaline solutions; the minerals associated with the ores at Goldfield show, however, that the waters at the time of deposition were highly acid in character. To this type of deposition the name "alunitic and kaolinitic gold-quartz veins" is applied.

The geology of the district is comparatively simple: a basement complex of metamorphic rocks, intruded by masses of alaskite, probably in early Cretaceous, and overlain by a succession of Tertiary lava-flows and lake-beds. Of the lava-flows there are six rhyolites, a latite, three andesites, four dacites, and two basalts. The lake-beds are probably Miocene. All of these rocks have received a careful petrographical description.

Some ore-deposits occur in andesite, but most of them are in dacite. They are complex mineralogically, occurring in irregular tabular deposits which are approximately defined by the term metasomatic fissure veins. The most notable features of the ore-bodies are their remarkable richness and their equally remarkable irregularity. Three distinct types of wall-rock alteration are recorded; the first results in craggy outcrops of silicified volcanic rock, which form a marked feature of the topography; the second is a soft, light-colored mass of quartz, alunite, kaolinite, and pyrite; the third type is propylitic with the formation of calcite, epidote, chlorite, and pyrite. The ores are closely associated with the first two types of alteration, though the alteration is much more extensive than the ore deposits. It is the extensive formation of sulphate minerals, alunite, and kaolinite, in close association with primary ores, that gives to the deposits their chief genetic interest. The changes in the dacite have been carefully studied both qualitatively and quantitatively, as this method probably furnishes the best clue to the nature of the depositing solutions. The

theory reached by the authors is that of simultaneous solfatarism and oxidation. It is supposed that the ascending waters carried, besides the heavy metals, hydrogen sulphide, carbon dioxide, and alkalies. The hydrogen sulphide was oxidized near the surface to sulphuric acid, which, descending, met more of the uprising currents and caused the deposition of the ores.

The age of the ore deposits is placed in the late Pliocene, and it is thought that they were formed at a depth of not more than 1,000 feet.

E. R. L.

The Vertebrata of the Oligocene of the Cypress Hills, Saskatchewan. By LAWRENCE M. LAMBE. Contributions to Canadian Paleontology, Vol. III, Part IV. Canada Department of Mines, Geological Survey Branch. 64 pages of text and 7 plates.

The Oligocene of the district, composed chiefly of conglomerate, forms the capping of an extensive area of uplands, and lies unconformably on the Laramie. The vertebrate fauna, which has been known from these beds since 1883, has been correlated with the Titanotherium beds at Pipestone Springs, Montana. The publication of the present paper raises the number of species known from these deposits from 25 to over 50. Of these, seven species are of fishes, seven of reptiles, and the remainder of mammals; of the mammals two-thirds of the species belong to the Ungulata.

E. R. L.

Report on Tertiary Plants of British Columbia Collected by Lawrence G. Lambe in 1906, together with a Discussion of Previously Recorded Tertiary Floras. By D. P. PENHALLOW, Canada Department of Mines, Geological Survey Branch.

The report presents a very full account of the distribution and stratigraphic significance of the Tertiary floras of British Columbia. The localities are described at which Tertiary plants have been found, with lists of fossils from each locality; then the individual species are discussed briefly, with mention of the localities in which they are found; and following this is a discussion of the evidence of the floras of the several localities with regard to the age of the deposits and their relationship to similar deposits in other regions. The entire Tertiary flora falls into two groups belonging to the Eocene and the Oligocene periods. The report is rather poorly illustrated by a few text figures.

E. R. L.

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A CENTRAL AFRICAN GLACIER OF TRIASSIC AGE[1]

SYDNEY H. BALL AND MILLARD K. SHALER
New York City, N.Y.

INTRODUCTION

From June, 1907, to June, 1909, the writers directed the prospecting work of the Société Internationale Forestière et Minière du Congo in the Belgian Congo, more familiarly known by its former name, the Congo Free State (Fig. 1). In the zone of the Maniema (Fig. 2), in the eastern part of the colony, evidences of glacial action of Jura-Triassic age were noted, which seem worthy of description.

The data of a scientific nature were collected during the two years passed in the Belgian Congo, incidental to an economic reconnaissance of the country, and is consequently of a fragmentary character. Difficulties of work in a partially explored tropical country also explain the lack of detail in this paper. Topography by R. B. Oliver is the base used, and field notes by A. E. Smith are drawn upon in the preparation of this paper.

LOCATION AND AREA

Belgian Congo lies in southwestern Central Africa to the west of the Continental Divide. It has a coast line of but twenty miles on the Atlantic, but widens rapidly eastward to points 5 degrees north and 14 degrees south of the equator. Its area is 908,000

[1] Published by permission of the Société Internationale Forestière et Minière du Congo.

square miles, or greater than that of all the United States east of the Mississippi River.

The zone of the Maniema is situated in the Upper Congo region, and includes that part of the Lualaba (Congo) Valley between latitudes 3 and 5 degrees south. The principal state post in the zone is Kasongo (Fig. 1).

TOPOGRAPHY AND DRAINAGE

From north to south, Africa is made up of three topographic elements: the Atlas Mountains, a highly accentuated region of closely folded rock; the Soudan and Sahara desert region, a more or less accidented plain in which the rocks are, in the main, flat-lying; and the central and southern tablelands with the Abyssinian plateau, consisting of intensely folded older, and horizontal younger rocks.

The Belgian Congo lies within the plateau region, and consists from west to east of: (1) a narrow coastal plain, which faces the Atlantic Ocean, rising to (2) an ancient mountain range, now eroded to an intensely dissected plateau, and frequently referred to as the Crystal Mountains (the higher domes reach an altitude of 2,300 feet; through the hard rocks of this plateau the mighty Congo rushes in a series of rapids, and low waterfalls, the non-navigable stretch between the Lower and Upper Congo rivers); (3) the great interior region, a basin whose slopes rise gently from Lake Leopold II (altitude 1,110 feet). The limits of the basin to the north (altitudes from 2,500 to 4,200 feet) and to the south (from 4,000 to 5,000 feet) are comparatively low, but to the east rise the Eastern Frontier Mountains, in height averaging about one mile above sea-level. Certain peaks like the volcanic Ruwenzori (altitude 16,800 feet) rise to altitudes exceeding 15,000. These mountains are in part due to folding, but largely to north-and-south faulting with which are genetically connected important volcanic phenomena.

The Congo River and its tributaries drain the Belgian Congo with the exception of a small area in the extreme northeastern part, the waters of which find their way into the Nile. The principal affluents of the Congo are the Kasai, Sankuru, and Ubangi. It is 4,640 kilometers in length, and the sixth longest river in the world.

GENERAL GEOLOGY (Fig. 1)

The coastal plain is underlain by marine sandstones which are inclined gently toward the ocean. The sandstones, which are covered by recent alluvium at the Congo mouth, are considered by geologists who are familiar with them to be of Tertiary and Cretaceous age.

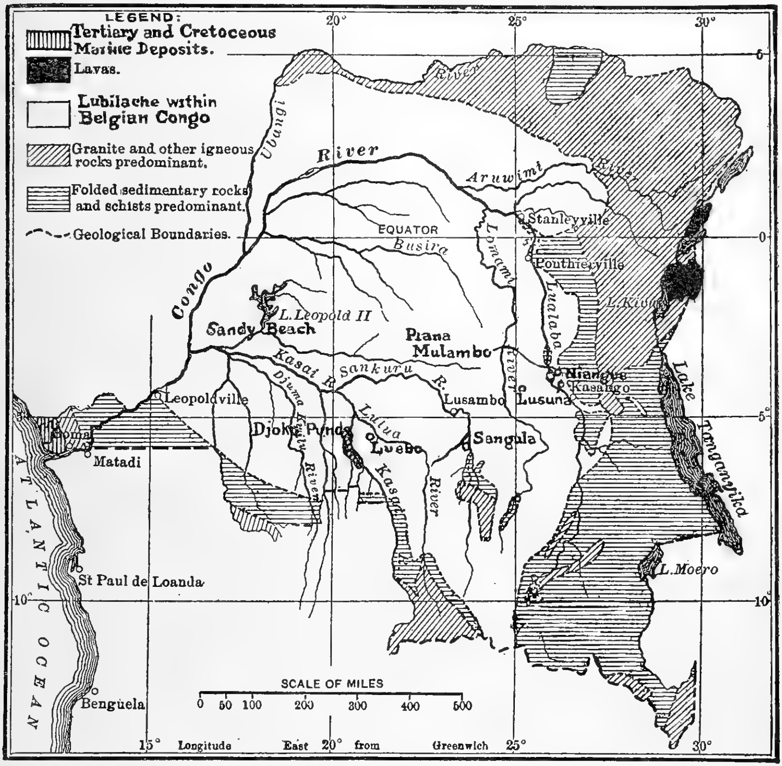

FIG. 1.—Showing approximate geological boundaries in the Belgian Congo

The so-called Crystal Mountains consist of older rocks, the age of which has not yet been satisfactorily determined. The older members of the series consist of mica schists and sericitic quartzites, interbedded with which are chlorite and epidote schists, representing either basic lavas contemporaneous with the sedimentary rocks, or very ancient intrusive bodies of igneous rocks.

Of later origin are intrusive masses of granite and gabbro, now

mashed and recrystallized into gneisses. Large bodies of granite and smaller ones of diabase also occur.

To the east of these older rocks are limestones and calcareous schists, which near the ancient complex are closely folded, but are flat-lying farther east, half-way between Matadi and Leopoldville. These beds are considered by E. Dupont[1] to be of Devonian age. To the east they are unconformably overlain by red sandstones and shales, the Kundulungu (Permo-Carboniferous) of Professor Jules Cornet.[2]

The great interior region is covered by the Lubilache formation, a series of interbedded sandstones and shales, either flat-lying or dipping gently toward the center of the basin. The formation, the lower surface of which is undulating, thins rapidly on the upper slopes of the basin. As the rim of the basin is approached, isolated inliers of older folded and faulted rocks begin to appear where valleys cut through the sandstone-shale blanket, and encounter low domes on the old surface.

These older rocks are similar, in a general way, to those of the Crystal Mountains. They consist of very ancient mica schists, quartzites, and igneous schists and gneisses, which are cut by gabbros and granites. Younger than the granites are folded sandstones, quartzites, slates, shales, and limestones. Cornet is, without much question, correct in his belief that these two series of rocks are respectively of pre-Cambrian and Paleozoic age, although, unfortunately fossils have nowhere been found in them. In the Eastern Mountain area are also modern and Tertiary lavas.

The main structural features on the north and south rims of the Congo basin have an east-and-west trend, while the rocks of the Eastern Mountains strike north-and-south. The position of Lakes Tanganyika, Kivu, Albert Edward, and Albert and of the mountain ranges near by has been determined largely by faults, the trends of which are approximately parallel to the strike of the rocks.

[1] *Lettres sur le Congo* (1889), Paris.

[2] *Bulletin Société Géologique de Belgique*, XXI, 262.

LUBILACHE FORMATION

The Lubilache formation, in which the glacial features occur, was first described by Dupont[1] and named by Cornet[2] from the Lubilache (Sankuru) River, where it is typically developed. It is the essentially flat-lying sandstone-shale series which covers the central Congo basin, not rarely extends in tongues into the rim plateau and mountain regions, and at several points crosses beyond the Congo basin. In general this series is made up of sandstones and shales in alternating beds, which grade into one another both laterally and vertically.

As a rule massive bedding predominates in the sandstones as does a reddish color; grayish and white beds are, however, not uncommon.

In the lower Kasai region particularly, a quartzitic phase is often developed in the sandstones by the deposition of secondary silica by surface waters. In extreme instances this action results in a rock almost cherty in character, which is often cellular, the weathered surface being pitted. In the upper Kasai and Sankuru regions this quartzitic phase is rare, the sandstones being medium grained and having usually a saccharoidal texture. In the Lualaba (Upper Congo) area hard, fine-grained maroon sandstones cemented with a ferruginous pigment predominate. In all cases the sandstones are typically quartzose, although near the base of the formation at many places, feldspathic material is present.

The shales are usually fissile and vary in color from greenish gray to tan and drab.

In the vicinity of Nyangwe, on the Lualaba River (Upper Congo), shales, well exposed, are more or less bituminous, but grade laterally both up and down the river into more arenaceous beds. West of Kasongo, toward Lusunu, these beds are almost sandstones.

The basal beds of the formation are generally slightly conglomeratic. In the vicinity of the junction of the Lulua and Kasai rivers the ancient erosional surface upon which the flat-lying sandstones and shales were deposited undulated very gently. The down-cutting of the stream valleys has exposed, at numerous

[1] Dupont, *op. cit.* [2] Cornet, *op. cit.*, XXI, 211.

places, the summits of the greater elevations of this ancient surface. While the contact is poorly exposed, the basal beds are seen to be nowhere coarsely conglomeratic nor to contain many pebbles. The well-rounded pebbles consist of quartz, chert, and granite, all probably derived from the so-called pre-Cambrian series. They are usually confined to the twenty feet immediately above the contact, although in instances they occur considerably higher.

Between Luebo and Lusuna, where the base of the series is not seen, conglomeratic beds or lenses were noted interbedded with sandstone. In the Lualaba Valley within the zone of the Maniema a basal conglomerate, which will be described later, is frequently exposed in the valleys of the streams.

The vertical range between the base and top of the Lubilache is probably somewhat greater than 1,500 feet. At no one locality however, known to the writers, is this entire thickness exposed. In the upper Kasai region, between Luebo and Djoka Punda, monadnocks, principally of massive red sandstone of this series, rise 400 feet above the general plateau level, and 700 feet above the river at the places named, thus exposing approximately 700 feet of this formation.

In the Maniema the base of the series is considerably higher than in the Kasai region, the base averaging 2,000 feet in the former, and 1,550 feet in the latter region. As the beds were deposited in what appears to have been one and the same lake, this difference in elevation is due probably to north-and-south faults parallel to Tanganyika Lake. These successively have raised the country from west to east upward. Evidence of this is seen in the isolated outlier of sandstone in the Luiko Valley, later to be described (see p. 691).

Initial dips up to 5 or even 10 degrees were noted in the zone of the Maniema, particularly where the sandstone occupies ancient fjords extending up into the old mountains, and a slight initial dip occurs away from the mountain masses toward the center of the larger basins of deposition. For the most part, however, the formation is essentially flat-lying, and with few exceptions the dip can be measured only in feet per mile and not in degrees.

AGE OF THE LUBILACHE

Studt,[1] from general stratigraphic relations, considers the Lubilache in the Katanga to be the equivalent of the Stormberg member (Trias) of the Karoo. This correlation is confirmed by fossils collected by us. While these plant and animal remains are of a fragmentary character, they are nevertheless sufficient to place rather definitely the horizons from which they were collected. Dr. E. O. Ulrich, of the U.S. Geological Survey, kindly determined the fossils, and places the age of the series probably in Jura-Triassic time. Fossils were found by us, and described by Dr. Ulrich as follows: Shale from Niangwe, 200 feet above base of Lubilache series: "Fragments of plants undeterminable."

Chert from Sandy Beach (on Congo, 130 miles above Leopoldville) perhaps 150 feet above base: "Probable broken sponge spicules and suggestions of branching sponges."

Limy shales ten miles below Stanleyville and 150 (?) feet above the base of series, Dr. Ulrich states:

These are crowded with Ostracoda and with these fewer bivalved phyllopods and fragmentary dermal ossicles of ganoid fishes. So far as observed the Ostracoda belong to fresh and brackish water species of *Cypris* and *Candona* and perhaps other genera of Cypridae. Unfortunately the form in these Ostracoda is very similar in species, ranging from Pennsylvanian on to recent times. But the alliances of your specimens seem to be rather nearer Mesozoic species than to Tertiary. . . . .

With the Ostracoda I find a single valve of a neat *Estheria*. The surface ornament appears minutely radiate under a hand lens but more closely examined is found to consist of sharp radially disposed bars crossing the flat spaces between the concentric ridges. This type of ornament is found in two recent species (*E. donaciformis* and *E. similis* Baird) and also in two Mesozoic species (*E. elliptica* Dunker and *E. subquadrata* Sowerby), but the Stanleyville species evidently differs in outline from all of these and doubtless represents a distinct, probably new, species. The fish remains are too fragmentary to be determined.

Mr. R. Kotska, prospector of the Lower Congo–Katanga Railroad, found a fossil crustacean at Sangula at the confluence of the Buschinmai and Sankuru rivers. This specimen has been turned over to us through the kindness of officers of that company. The prospector, a man with considerable geological knowledge, describes

[1] *Annales du Musée du Congo*, série II, "Katanga" (Bruxelles, 1908), 14.

the rock as flat-lying, "grès tendre," the common Belgian name for the Lubilache formation. The matrix in which the fossil occurs is typical of the soft sandstone seen by the authors at Lusambo, 60 miles to the north of Sangula. There is then no doubt in the minds of the writers that this is from the Lubilache formation. Concerning this fossil Dr. Ulrich says:

> It is a bivalved crustacean, apparently of the genus *Estheria:* and so far as known to me the largest species of this genus yet found. The species seems distinct from all the described forms.
>
> Looking over the fossils again, my belief has grown to conviction that the bed from which these fossils were procured is Mesozoic and Jura-Triassic, rather than later.

While the fossils are by no means strongly indicative of the climatic conditions under which they lived, Dr. Ulrich states that if they indicate anything concerning the climate it would be that it was relatively moist and rather cool. The water was either fresh or brackish.

DEPOSITION OF THE LUBILACHE

The Lubilache formation was deposited in a Triassic lake of fresh or brackish water, which may have been connected with the ocean. On the railroad at kilometer 115, in the Lower Congo, residual bowlders of what one of us (S. H. B.) takes to be the Lubilache formation, occur on the west side of the present divide of the plateau, commonly called the Crystal Mountains. It is hence more than probable that this ancient lake was once connected with the ocean by one or more straits. From the present distribution of the Lubilache beds this lake was at least 900 miles in diameter, and was probably much larger. The bed of the lake was an undulating surface, and the body of water was surrounded by low land to the west, north, and south, but with at least hilly country to the east. These eastern hills in instances must have been 2,000 feet high. Between them ran valleys, some of which appear to have been deep and abrupt enough to have been worthy of the name of "fjords." While the Lubilache was being deposited it is more than likely that the central part of the lake basin around the present Lake Leopold II was a sinking area. At no time does the lake appear to have been deep, except in certain valleys extend-

ing into the mountains. Cross-bedding is common, as are rapid changes from sandstone to shale, probably best to be interpreted by current scouring. The nature of the sediments indicate deep disintegration of the rocks near the shore, while from the fossils Dr. Ulrich is inclined to believe the water to have been at least cool.

LUBILACHE IN THE ZONE OF THE MANIEMA

In the Maniema zone in the Lualaba Valley and in the valleys of its tributaries, west of the Eastern Frontier Mountains, the Lubilache covers a large area, as shown in Fig. 2. Within the zone isolated hills and mountain groups of older granites, gneisses, schists, and folded sedimentary rocks rise above the dissected plain of the flat-lying series. These older rocks probably stood as islands in the lake in which the Lubilache was deposited.

The general character of the beds of this series has been described, but a more detailed description of the basal beds will be given, as it is at this horizon that evidences of glacial action were noted.

LUBILACHE BASAL CONGLOMERATE IN THE MANIEMA

The basal beds are best exposed along the Lualaba River, and the lower Lulindi, and here they have an entirely different character from elsewhere in the Maniema and other districts, as known to the writers. Indeed very coarse conglomerates at the base of these flat-lying sandstones and shales are confined to the immediate valleys of these streams. Elsewhere where the conglomeratic phase occurs the pebbles are rarely over an inch in diameter and sparsely distributed. This is true even where conglomeratic beds occur around the hills of granites, schists, and other older rocks.

In the immediate valley of the Lualaba and lower Lulindi rivers, between 3° 30′ and 5° south of the equator (our work did not extend south of the 5th parallel) the basal 5 to 20 feet of the Lubilache is an exceedingly coarse conglomerate. This conglomerate is morainal material, deposited by a tongue of a glacier which followed down the Lualaba Valley probably prior to its becoming a gulf of the great body of water in which the Lubilache was deposited. The morainal matter appears to have been but slightly reworked by the waters of the lake.

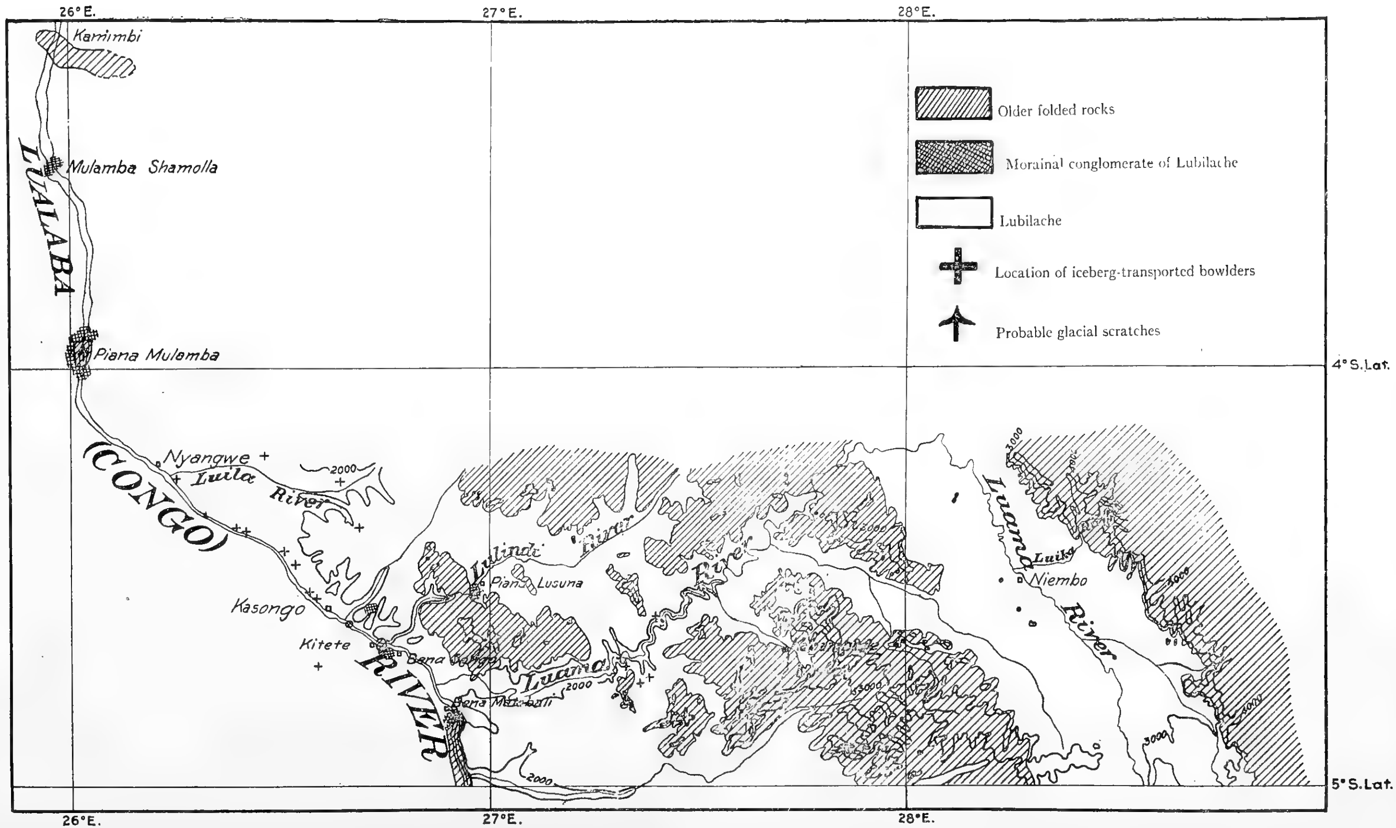

FIG. 2.—Map of Maniema. Scale $\frac{1}{2,000,000}$ (after indicated reduction); contour interval 1,000 feet

Before the formation of the great interior lake or sea in which the Lubilache was deposited the Congo Valley was probably a most important depression and after the subsidence the upper portion of the valley formed a wide but rather shallow gulf with arms reaching in instances into valleys of the eastern mountain range itself. A small isolated remnant of flat-lying sandstone having the general lithologic character of the upper beds of the Lubilache, as exposed in the Maniema, was found in the Eastern Mountains in the Luiko Valley. This outlier is only a few feet in thickness, and lies in a small tributary valley on an uneven, eroded surface of gneiss. Its elevation above sea-level is about 4,800 feet, or nearly 2,000 feet above the highest horizontal rocks known in the region, the sandstone forming Niembo Mountain near Niembo (Fig. 2). This great difference in elevation is due to profound north-and-south faulting along the western front of the Eastern Mountains, but the presence of horizontal sandstone beds in a small valley at a considerable distance from the main area of flat-lying rocks is unquestionably due to its having been deposited in an antecedent valley, the sides of which protected it from complete removal by erosion. This outlier, and the residuals of apparent Lubilache in the Bas-Congo, show that this formation once had much wider distribution than at present.

A type of the Lualaba River basal beds is exposed along the Lulindi River, just downstream from the crossing of the telegraph line, and near the village of Piana Lusuna. This is fifteen miles from the present Lualaba River, and 275 feet above it at Kasongo. The older rocks unconformably underlying the Lubilache are not exposed here, but typical basal beds occur for 200 feet laterally along the river. The matrix of the conglomerate is a yellow, incoherent, fine-grained, slightly argillaceous sandstone. The exposure is apparently flat-lying. Small bodies are wholly without bedding, others are thinly laminated, while still others have a swirly bedding, the thin laminae curving in concentric bands. Cross-bedding is not rare. The distribution of the bowlders and pebbles is patchy; areas 2 to 40 feet across being without pebbles, while between are heavily conglomeratic areas. In the same conglomeratic mass coarse sand and bowlders 4 feet across occur. The smaller pebbles

are usually well rounded; the larger are angular or only roughly rounded; the medium-sized bowlders, those from 2 to 6 inches in length, are three or four cornered and often striated.

The striations are especially well seen on dense, close-textured rocks, quartzite for example (Plate I). These can scarcely be other than glacial striations. While through desert erosion somewhat similar scratches are produced, they are too abundant here on a single bowlder, and the familiar tiny crescentric fractures (nicks), caused by the striking of one bowlder by another in descending the cloud-burst swept valleys of arid regions, are absent.

With but slight variations this description would answer for the exposures on the Lualaba River at the Kitete Rapids where the Lubilache is in contact with quartzite; at Bena Songo and Bena Matabali Rapids; at Piana Mulambo where the Lubilache lies on slaty quartzite more or less folded; and at Mulambo Shamola. The principal and most constant differences lie in a slight variation in the character of the matrix, which varies in color from whitish yellow to greenish gray or dark gray, and in the degree of consolidation. The matrix, which is usually incoherent, is well consolidated at Piana Mulambo and Mulambo Shamola. At Bena Songo the irregular distribution of the bowlders is well seen, many occurring for 100 feet laterally, and none in the next 100 feet.

Where the underlying older rocks are exposed the bowlders derived from them are more abundant and more angular than the bowlders of other varieties. The bowlders and pebbles consist of quartzite, of granites and gneisses, of limestones, etc. It is worthy of note that at the most northerly of these outcrops of basal conglomerates at Mulambo Shamola, the larger pebbles are but six inches in diameter. There are at all other localities great bowlders two to three feet in diameter, of rocks not known to occur in the immediate vicinity, that is, large bowlders which have been transported considerable distances. Typical examples of the contact of these basal beds with the older rocks are seen in Fig. 3, A and B representing respectively the contact with quartzite at the head of the Kitete Rapids, and the contact with slaty quartzite at Piana Mulambo.

PROBABLE GLACIAL SCRATCHES

Piana Mulambo is situated on the Lualaba River about fifty miles northwest of Kasongo (Fig. 2). One-quarter mile east of the house of the transport agent of the Grand Lakes Railroad at this village is a swift rapid in the river. On the west bank of the river, at the lower end of the rapids, highly inclined slaty quartzite beds are at the same elevation as the base of the Lubilache at the house mentioned. Fig. 3B represents the contact one mile south of the house. The slaty quartzites, owing to the differences in resistance to erosion of their beds, usually weather as sharp-crested ridges and saddles, but here and there are flat surfaces. On the upper surfaces and never on the sides of these flat exposures of the older rocks are peculiar gouges and scratches (see Fig. 4).

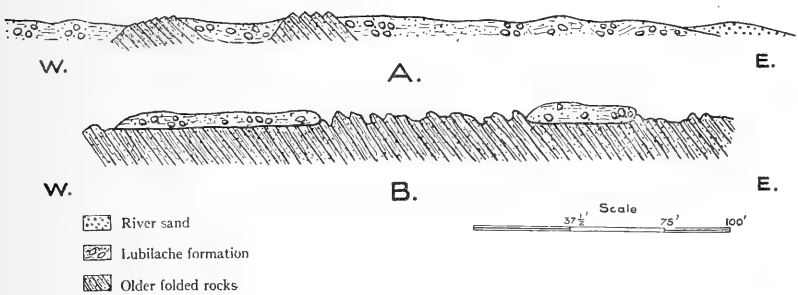

FIG. 3.—Contacts of Lubilache and older rocks on Lualaba River. A, Kitete Rapids; B, Piana Mulambo Rapids.

Coursing a little east of north and west of south these gouges and scratches have a rude parallelism. Some are cylindrical depressions from one to five feet long, and from one-half to three inches wide and deep. The ends are as a rule cigar-shaped and the surfaces of the grooves are striated with fine scratches from $\frac{1}{16}$ to $\frac{1}{4}$ inch apart. At the southern end is frequently a bowl-like depression, more deeply cut than the rest of the gouge. Local smoothings of the rocks occur finely striated with parallel scratches and in direction similar to the gouges described. At one place are three crescent-shaped gouges which course from east to west, with the concavity to the south. These, which resemble "crescentric gouges," are four inches in length, the central one being deepest and broadest (see Fig. 4).

These gouges occur level with the contact elsewhere, and do not resemble any river-worn scratches with which we are familiar. The grooves, crescentric gouges, and the finely striated planed surface appear to be of glacial origin, and indicate that the glacier once extended to at least this point, or to 4° south latitude. The glacier, from this evidence, advanced from south to north.

ERRATIC BOWLDERS

In the immediate Lualaba and Luama valleys in the Maniema, and for several miles on either side between Nyangwe and the

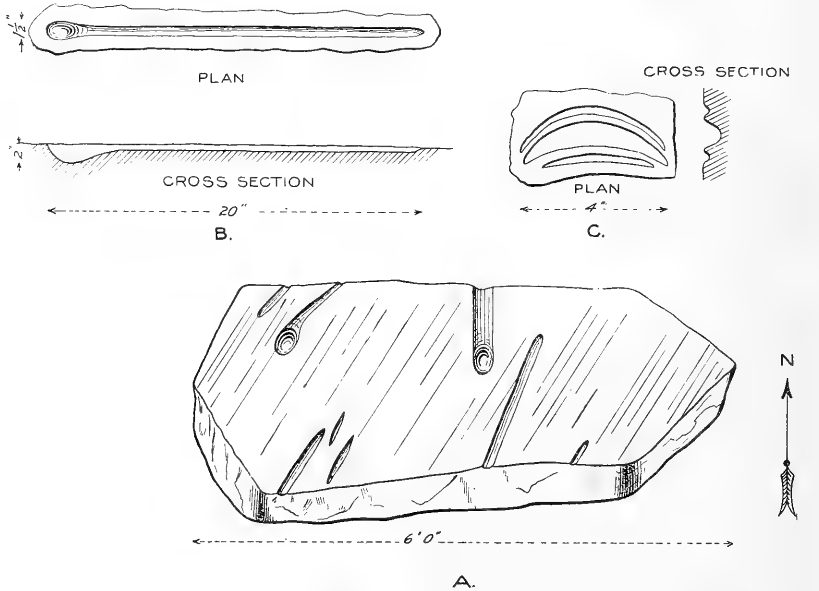

FIG. 4.—Probable glacial grooves and scratches on Paleozoic slaty quartzites, Piana Mulambo Waterfall, Lualaba River.

5th parallel south, the shale of the Lubilache has sparsely and irregularly scattered through its mass, pebbles and bowlders with a maximum diameter of five feet. These bowlders are not known to occur within the large areas of the Lubilache away from these rivers. They are usually well rounded, and consist of granites, quartzites, diorites, and other older rocks. There is in no case any change in the fineness or character of the well-laminated shale immediately surrounding these isolated bowlders.

The laminae of the shale are concentric with the form of the bowlders, being slightly arched over, and greatly bowed under them, as if they had been dropped from considerable heights into a plastic mass.

Within the limits defined these bowlders occur at numerous localities, as shown in Fig. 2, at stratigraphic positions from 0–200 feet above the base of the formation. Two exceptions should be noted: At Bena Tomba, latitude 4° 30′ S., on the bank of the Lufubu River, and at Tubila on the Lualaba, latitude 1° 30′ S., bowlders of older rocks lie upon the surface. The underlying rock is the Lubilache shale. The source of these bowlders is not known; they may have weathered from the shale, or they may have been carried to the points named by the natives, by whom such hard rocks are used in grinding foodstuffs.

The largest bowlder noted is of granite and was found by Smith, about one mile north of the Luila River. This bowlder measured $5 \times 3 \times 3\frac{1}{2}$ feet. Numerous other large bowlders were noted in the shale northeast of Kasongo.

From the fineness of the inclosing shale, the size of these bowlders, and their great distance in many cases from their source, it is evident that they were dropped from some object floating on the surface of the body of water in which the Lubilache was deposited. They could have been transported in but one of two ways: (1) by being imbedded in the roots of floating trees, or (2) by being carried by icebergs.

That bowlders of such enormous weight could be transported in the roots of floating trees is improbable. Furthermore, the shales of the Lubilache are practically barren of vegetable remains, particularly fossil tree trunks; absolutely none of the latter having been noted. The bowlders are numerous along the Lualaba and are known nowhere else in the formation. It is scarcely conceivable that the shores of this portion of the basin of deposition were alone bordered by trees capable, when swept into the lake, of transporting bowlders of several tons weight in their roots. Moreover, fragments imbedded in tree roots are usually not only angular or subangular, but also small and of weathered rock; while in all cases the erratic bowlders of the Lubilache shale are rounded or

subangular, and are frequently large and fresh. Further, at several places the bowlders are in excess of what can be considered the load of one tree. In shales elsewhere in the world which are known to have been deposited in lakes or seas with tree-lined shores, similar bowlders occur in but few instances.

We believe, then, that these bowlders were transported by icebergs, derived from glaciers, and which melted where perhaps arrested in their courses by cross-currents.

Nyangwe was apparently the northern limit to which these icebergs reached, although below Nyangwe the immediate Lualaba (Congo) Valley only was examined. From Nyangwe to 5° S., however, in almost every mile of Lubilache exposures traversed, these erratics were noted. As the morainal conglomerate extends south of Nyangwe, we have perhaps evidence here of the southward retreat of the glacier in early Lubilache times.

RÉSUMÉ OF EVIDENCES OF GLACIATION

It is concluded from the evidence given above that during Triassic time at the beginning of the deposition of the Lubilache series, a glacier, or glaciers pushed in a tongue down the present valley of the Lualaba River; from the fact that large bowlders, probably dropped by icebergs, are found at least 200 feet above the base of the formation, it is believed that long after the glacier had retreated toward the south, glaciers still existed to the southeast. This glacial epoch, therefore, must have been of a considerable duration.

The glacial features presented by the Lubilache formation contiguous to the Lualaba Valley in the Maniema are:

1. Striations, having the characteristics of glacial striations, on pebbles in the basal conglomerate of this series, indicating morainal origin.

2. The tongue-like form of the basal Lubilache beds in the Lualaba Valley, and the character of this conglomerate, including the size of the bowlders, the lack of assortment, the patchy arrangement of the material, and the preponderance of bowlders of local origin.

3. Erratic bowlders, presumably dropped by icebergs, occurring

in shales of this series as far north as the latitude of Nyangwe which have been seen only near the Lualaba Valley.

4. Probable glacial scratches, crescentric gouges, and smoothings on the surfaces of older rocks upon which the Lubilache was laid down.

The presence of glaciers being, in the writers' mind, proved by the above evidence, it remains to determine, in so far as possible, the character of the glaciers, the climatic condition under which they existed, their extent, and their relation to the Permo-Carboniferous glaciers of South Africa.

AFRICAN EQUATORIAL GLACIERS OF THE PRESENT DAY

Chamberlin and Salisbury[1] state that in equatorial regions the snow line has an altitude of from 15,000 to 18,000 feet.

Small mountain glaciers are known on three of the highest peaks of equatorial Africa. Hans Meyer[2] found on Kilima Njaro (3° S.) small glaciers with lower limits at an elevation of 4,300 meters (14,100 feet). On Ruwenzori (1° N.) E. S. Moore[3] found several glaciers with the snow line at 13,500 feet above sea-level.

Scott Elliot[4] gives the snow line on this same mountain as 15,500 feet. J. W. Gregory[5] found glaciers on Mount Kenia situated on the equator. The lower ends of these glaciers are 15,500 feet above sea-level; the snow line being at 16,000 feet. Scott Elliot[6] believed that formerly glacial action extended to 5,200 feet on Ruwenzori. Gregory[7] found evidences of old glaciers on Kenia at about 10,000 feet, and Meyer[8] states that on Kilima Njaro the glaciers once pushed down to lower levels. Among certain geographers the conclusions concerning these Pleistocene glaciers are doubted.

[1] *Geology*, I, 246.

[2] Hans Meyer, *Verhandlungen der Gesells. für Erdkunde der Berlin*, XXVI (1899), 100.

[3] *The Tanganyika Problem* (London, 1903), 102.

[4] *A Naturalist in Mid-Africa* (London, 1896), 175.

[5] *Geographical Journal*, IV (1894), 419–20.

[6] Elliot, *op. cit.*, 172.

[7] Gregory, *op. cit.*

[8] Meyer, *op. cit.*

PROBABLE ELEVATION OF LUBILACHE BEDS WHEN DEPOSITED

The base of the Lubilache formation at Luebo at the present day is 1,475 feet above sea-level. In the Maniema, due to uplift by north-and-south faults, the basal beds lie at a higher elevation (1,800 to 2,400 feet), while near Lake Leopold II (1,110 feet), through subsidence of the beds, the country rock is well up in the Lubilache. It is believed that the elevation of the basal beds at Luebo is considerably above that of the lake bottom in which the Lubilache was deposited. It has before been mentioned that residuals of what appears to be the Lubilache formation were found in the Lower Congo, indicating that the lake was probably once connected with the ocean. Other evidence also points to the uplift in later geological times of the Crystal Mountain region to an elevation of 3,400 feet above sea-level. On the coast there is an indistinct zonal distribution of the Tertiary and Cretaceous sedimentary rocks, the later being farther inland. The Crystal Mountains themselves are a peneplain, which has been uplifted presumably by faults coursing west of north and east of south. The Congo River valley through the Crystal Mountains is young topographically and indicates recent uplift, and yet the amount of erosion which the peneplain has suffered would lead one to place its development back at least as far as the Cretaceous. At some time then during or prior to the Cretaceous we may believe the Congo basin to have been practically at sea-level. All evidence at hand indicates that the Lubilache formation was laid down in a lake of which the bed was at, or but slightly above, sea-level.

Only to the east did high hills arise, and from the lack of bowlders in the Lubilache immediately surrounding these hills, it is doubted if they reached a maximum elevation of over 2,000 feet above the lake surface.

SIZE OF GLACIER

The known extent of the morainal basal conglomerate in the Maniema (at least 100 miles from north to south) is many times greater than any tropical glacier now existing. Further, if the bottom of the Lubilache lake was at as low an elevation as we believe it to have been, we must rank this glacier in size with glaciers of the Malaspina type, if not with continental glaciers.

CLIMATIC CONDITIONS

Dr. Ulrich is inclined to believe the fossils indicate cool waters, and the writers think that, while the glacial conditions were induced partially by the altitude of the region in which they formed, they were largely due to climatic changes. At present, due to faulting comparatively recent in the geological sense, some of the mountains between the Lualaba River and Lake Tanganyika are 9,000 feet high. It is doubtful whether as great elevations existed in the Maniema during Lubilache time.

LOCATION OF THE GLACIER

The position of the glacier can be located only in a most general way. It appears to have been south of the Maniema.

The disappearance of the glacial conglomerate and the iceberg-borne bowlders to the north indicates that the source of the glacial material was to the south. Of similar import is the fact that the supposed glacial striations have a north-and-south orientation, while the concavity of the crescentric gouges indicates a movement from south to north.

Toward the south the work of the writers extended only to the fifth parallel. Professor Cornet's work in 1901–3 was within the Katanga, between latitudes 8° and 12° S. and longitudes 28° to 23° 31′ E. Between Professor Cornet's work and the fifth parallel, lies a considerable area in which the geology has not been studied even in reconnaissance.

To the southeast of Kabambare are mountains where these glaciers probably existed in Lubilache time, reaching today elevations of 9,000 feet; in Lubilache time they were presumably not so high. The Luama River heads in these mountains, and as the erratic bowlders are found along its course, as well as that of the Lualaba, it is possible that the valley then existed and that the glacier pushed north and then west and northwest from these mountains to the Lualaba.

Another possible but not probable location of the glaciers is found in the mountains to the northeast of Kasongo, the glaciers descending the Lulindi River to the Lualaba, thence being deflected northward along its valley. Northwest of Neimbo (Fig. 2) and

in other places in the Kabambare region at the contacts between beds of Lubilache and the older rocks, conglomerates are notably absent, which argues against a source of the glacier in the general region of Kabambare.

RELATION TO PERMO-CARBONIFEROUS GLACIATION IN SOUTH AFRICA

It has long been recognized that the Dwyka conglomerate at the base of the Karoo formation in South Africa is a glacial moraine, more or less reworked by water. These continental glaciers of Permo-Carboniferous age lay to the north of Cape Colony,[1] and from this center pushed southward.

The most northerly occurrence[2] of this conglomerate is in latitude 25° 40′ S.

The Stormberg beds, with which former Congolese geologists have correlated the Lubilache, is a much younger formation of Rhaetic age (close of Triassic); while, as Cornet[3] believes, the earlier Karoo members are probably represented by red sandstones named by him the "Kundulungu" formation. The fossil evidence here presented strengthens greatly this correlation.

When the Lubilache lake formed, a tongue of morainal material probably covered the Lualaba Valley. The bowlders, however, composing it are believed to be too fresh for it to have been the deposit of a Permo-Carboniferous glacier. Were such the case, weathering throughout Triassic time would almost certainly have destroyed the bowlders. Moreover, well up in the Lubilache formation iceberg-transported bowlders occur, indicating the presence of glaciers at that time somewhere to the south.

The source of the glaciers at the two periods appears to have been in the same general region, and it is possible that, in some area in northern Rhodesia or southern Belgian Congo, glaciers existed for the greater part of Permian and Triassic time.

[1] A. W. Rogers, *The Geology of Cape Colony* (London, 1905), 413.

[2] See map of Transvaal, by T. H. Hatch and G. S. Corstorphine, *The Geology of S. Africa*, London, 1905.

[3] Cornet, *op. cit.*, 413.

RÉSUMÉ

The geology of Central Africa is as yet too little known to discuss the possible bearing of this ancient glacier within the tropics upon the broad problems of general and glacial geology. It suffices to state that there appears to be reason to believe that in Triassic times, when tropical life flourished in polar regions, a temperate or coolish climate existed to the west of Lake Tanganyika in Central Africa 4° 30′ from the equator.

Knowlton[1] in describing the Triassic flora states that it indicates that there were "no or but slight seasonal changes due to alterations of hot and cold or wet and dry seasons." It was "on the whole a moist, warm, probably at least subtropical climate."[2] He mentions that Triassic floras have been found on the east coast of Greenland, and in Spitzbergen.

July 9, 1910

EXPLANATION OF PLATE

PLATE I.—Glacial-scratched bowlders; basal conglomerate. Lubilache formation, Lulindi River, near Piana Lusuna.

[1] *Journal of Geology*, XVIII, 107.

[2] *Ibid.*, 106.

THE PUERCO AND TORREJON FORMATIONS OF THE NACIMIENTO GROUP[1]

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CONTENTS

INTRODUCTION

The formations of the Nacimiento group are subjects of much interest to science because of the character of their vertebrate faunas and the positions they occupy in the time-scale of geologic history. The fossil mammals of the two formations have been carefully discussed by eminent paleontologists and yet but little is known of their areal distribution or stratigraphic occurrence. This paper is accompanied by the first contribution of detailed geologic mapping in the area of their type-localities, and is the result of research which has brought forward some important facts and thrown considerable light on the problem of their faunal and stratigraphic relationships.

The Nacimiento group was deposited during that long period of fresh-water conditions which prevailed over the greater part of western North America at the ending of the Cretaceous and the beginning of the Tertiary periods. In recent years paleontologists have considered the group as being earliest Tertiary in age, and thus marking the beginning of the Eocene series.

It is intended in the following pages to review the formations of this group, their correlations, etc., from the first discoveries to the present time and to set forth clearly the facts of their stratigraphic

[1] Published by permission of the Director of the United States Geological Survey.

Plate I

relationships in the light of new evidence; to present the first detailed geologic map of the upper Rio Puerco region; to discuss the physiographic changes which have taken place in that district between the close of the Cretaceous and the beginning of the Wasatch (Eocene); to present a list of fossil vertebrates with photographs of certain species apparently new to science; and to furnish a bibliography relating to the subjects under discussion.

HISTORY OF THE PUERCO

The Puerco formation was first described by Professor E. D. Cope in the *Annual Report of the Chief of Engineers to the Secretary of War* for the year 1875. His report deals with the geology of that part of northwestern New Mexico examined by him during the field season of 1874 when he discovered the Eocene deposits of what has since been called the San Juan Basin, from the river of that name which crosses it. This basin is in the extreme northwest corner of New Mexico and southwest corner of Colorado (see Fig. 1). On this map, the area inclosed by heavy black lines represents that examined by the writer in 1907 and is a miniature of the larger map presented herewith. The area described by Cope in connection with his Puerco formation is mainly along the east side of this district.

Inasmuch as the original description of Cope is of prime importance in the present discussion it is well here to quote his remarks on the Eocene Plateau or that portion of the San Juan Basin just west of the Sierra Nacimiento Mountains. In the following quotation, the names of formations referred to by Cope as correlated by the writer with those of the present time, are placed in brackets.

EOCENE PLATEAUS

West of the hog-back of Cretaceous No. 3 ["Laramie"] at an interval of perhaps two miles, at a point just north of the Gallinas Mountain, a sandstone bluff [Wasatch] presents a bold escarpment to the northeast. This is the angle of a mass of rock whose eastern face extends southward parallel to the mountain-axis, and whose strata dip first 15° and then 10° south, and soon disappear beneath a similar mass. This series [Wasatch] also presents an escarpment to the northeast, and its beds also dip 10° south, nearly opposite the cañon of the Gallinas. This façade rises to from 600 to 900 feet elevation, and is cleft to the base by a deep gorge, the Cañoncita de las Vegas. I traversed this fissure, passing entirely through to the elevated country to the westward. Six miles from its mouth is a large pool, fed by a spring known as the Mare's Spring. The cañon is narrow,

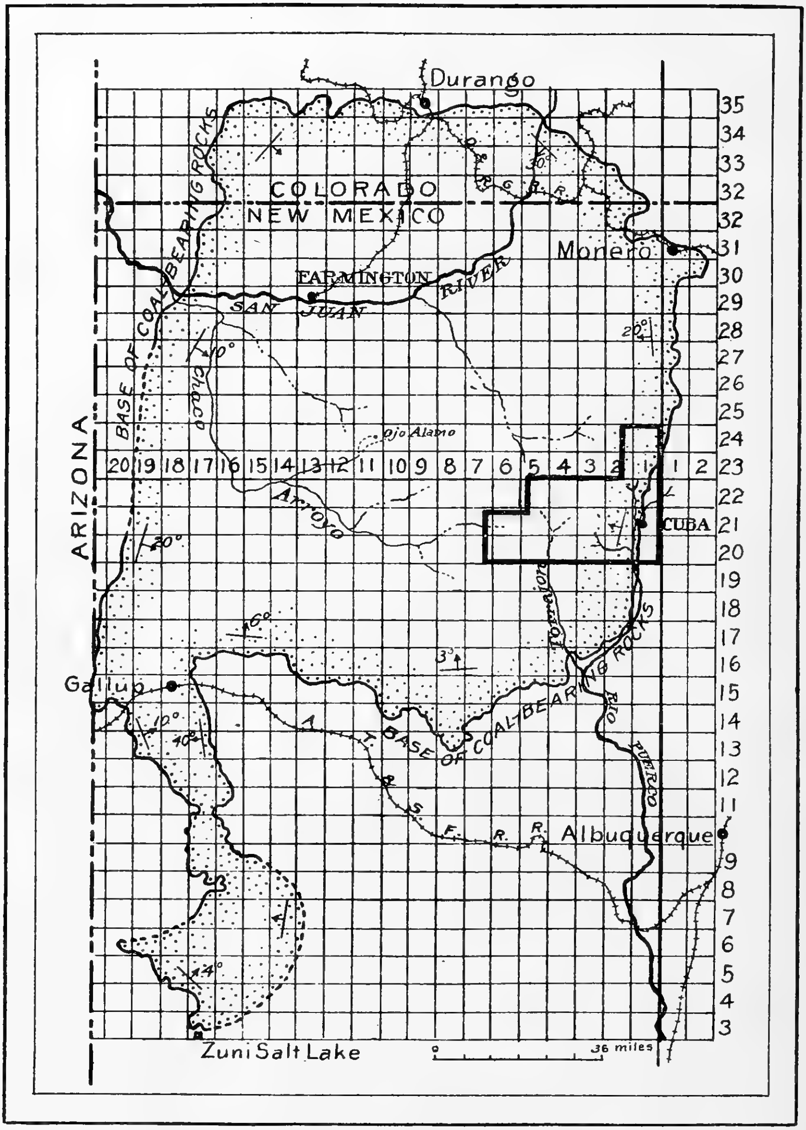

FIG. 1.—Sketch map showing relation of the Puerco-Torrejon locality to the San Juan Basin.

and the walls almost perpendicular. They are composed at the "puerta," or entrance, of a moderately hard, reddish-brown sandstone. The cañon is twenty miles in length, its bottom has a gentle rise; and as the sandstone has a gentle dip toward the west as well as south, its upper beds reach the level of the bottom at about the middle of the length of the cañon. Above them softer beds [Wasatch] appear, alternating with strata of sandstone; the beds are first gray, but others soon appear which are striped with red. The red-striped marls increase in relative thickness toward the west, and the sandstone strata diminish until at the head of the cañon the high lands fall off in masses of hills of bright-colored marls eroded into rounded and picturesquely formed hills. These extend in a long line to the north and the south, facing westward. To the west, a wide, elevated plain spread before us, varied with a few hills, and stretching away with a gentle slope to Cañon Largo and the country of the San Juan River. The discovery of the variegated marls was one of no little interest to the writer, inasmuch as I had made special efforts to find Eocene beds in this region, and they were now crowned with success. The position of these marls, with their close physical resemblance to the Wasatch beds of Bear River, Wyoming, together with the evidence furnished by a lower molar of Bathmodon, discovered by my guide, indicated that I had discovered the sediments of the great body of fresh water which during successive stages of the Eocene period occupied the drainage-basin of the Great Western Colorado. The thickness of the strata exhibited in the walls of the Cañoncita de las Vegas, I estimated at 1,200 feet.

On leaving the mouth of this cañon, and proceeding southward, the southern dip of the red sandstones [Wasatch] brings their summit to the ground-level in about ten miles' distance. The red and gray marls with alternating beds of white and yellowish sandstone [Wasatch] appear on their summits, and at a point twenty miles south of the cañon, form a mass of badland bluffs of from 600 to 1,000 feet elevation. This escarpment retreats and then turns to the east, forming an extensive horseshoe, the circumscribed area being occupied with hills and picturesque masses of sediment, with all the peculiar forms and desolation of badland scenery. I remained in camp for about a month near this circle, and obtained many fossil remains of vertebrates [Wasatch]. Ten miles south of this point another horseshoe of badlands covers an extensive area, and proved to be as rich in fossil remains [Wasatch] as the first. Here I made my second camp, remaining in it for three weeks. The southern boundary of the northern tract extends to within six miles of the Cretaceous hog-backs, while the corresponding part of the second approaches nearer, forming a line of bluffs of considerable height running north and south parallel with, and half a mile from, the hog-backs. Beyond the Puerco divide, hills of this formation rise on both sides of the trail, and near the Ojo de San José, the Eocene beds repose on the foot of the Nacimiento Mountains several miles to the east.

Below the sandstones which form the portals of the Cañoncita de las Vegas, another stratum of marls [Puerco] shows itself in hills of 100 feet and higher, in the sage-brush plain that separates them from the Cretaceous hog-backs. They

are soft and of mixed black and dark-green colors near the locality in question, and capped by light and yellowish sandstones. These are the lowest beds of the Eocene, and I traced them for forty miles to the south along the belt of country intervening between Cretaceous No. 4 ["Laramie"] and the reddish sandstone [Wasatch]. At the locality just mentioned they conform to the sandstones above, having a dip of 10° southwest, while they do not conform to the hog-back of Cretaceous No. 4 ["Laramie"], the nearest available outcrop, which dips at 25° west. Farther south this marl is represented by low hills of generally lighter color. Near Nacimiento it has an increased importance, as it rises both to the east and south. The valley of the Upper Puerco is excavated in it for some distance, and its blackish, greenish, and gray hills are seen on both sides of the river. At a point on the river about six miles below the village of Nacimiento, the lower sandstone of the Eocene forms a perpendicular bluff, which terminates in an escarpment of 500 feet elevation facing the south. The red-striped marls [Wasatch], having acquired a gentle northern dip, disappear from view some miles to the north, and the termination of the underlying sandstones warned us that we were approaching the southern border of the basin.

The border of the sandstone turned to the west at this point, the line of bluffs continuing as far as vision extended. Below and south of it, the varied green and gray marls formed the material of the country, forming badland tracts of considerable extent and utter barrenness. They formed conical hills and flat meadows, intersected by deep arroyos, whose perpendicular walls constituted a great impediment to our progress. During the days of my examination of the region, heavy showers of rain fell, filling the arroyos with rushing torrents, and presenting a peculiar character of this marl when wet. It became slippery, resembling soap in consistence, so that the hills were climbed with great difficulty, and on the levels the horses' feet sank at every step. The material is so easily transported that the drainage-channels are cut to a great depth, and the Puerco River becomes the receptacle of great quantities of slimy-looking mud. Its unctuous appearance resembles strongly soft-soap, hence the name Puerco, muddy. These soft marls cover a belt of some miles in width, and continue at the foot of another line of sandstone bluffs, which bound the immediate valley of the Puerco to a point eighteen miles below Nacimiento. Here the sandstone again turns to the westward presenting a southern escarpment of 500 to 1,000 feet elevation. I could not be sure whether this sandstone is identical with that of the escarpment twelve miles north, but suspected it to be such. [It is a lower sandstone and is Mesaverde.] Immediately south of it, low hills of Cretaceous No. 4 (?) [Mancos] extend across the Puerco [River] and continue south of the Eocene (?) bluffs at a distance of a mile or two with a western strike. They were as elsewhere of a soft yellowish sand and clay, including shale beds, and contained abundance of *Inoceramus*, like those found on the Gallinas.

Ten miles to the southward, the underlying Cretaceous beds are capped by a horizontal table of basalt (Mount Taylor flow) thus forming a mesa, through which the Puerco passed in a cañon. I supposed this to be the forerunner of

the great basaltic plateau which, according to Lieutenant Wheeler, constitutes the country south of the Rio Chaco for a great distance, one of little promise to the agriculturist. The season being well advanced, October 22, I thought best to commence the return march, which we accordingly did.

The soapy marls, or, as they may be called, the Puerco marls, have their principal development at this locality. I examined them throughout the forty miles of outcrop which I observed for fossil remains, but succeeded in finding nothing but petrified wood. This is abundant in the région of the Gallinas, and includes silicified fragments of dicotyledonous and palm trees. On the Puerco, portions of trunks and limbs are strewn on the hills and ravines; in some localities the mass of fragments indicating the place where a tree had broken up. At one point east of the river I found the stump of a dicotyledonous tree which measured five feet in diameter.

As already remarked, the Puerco marls belong to the Eocene series in their strict conformability to the superincumbent rocks of that age. They do not appear to represent the Fort Union or Lignite beds of northern Colorado and the North, as they differ in almost every respect. They contain no lignite nor coal, although their occasional black color may be due to a small amount of carbonaceous matter. They have no resemblance to the Fort Union beds in mineral character or fossils. I conclude, as a result of the investigation, that the latter formation has no existence in this part of New Mexico. The presence of such quantities of petrified wood gives weight to the probability that the Puerco marls are a lacustrine formation.

The geography of the greater part of the district referred to in the above quotation is shown on the topographic geologic map presented herewith. This map does not extend far enough northward by about seven miles to include the Canyoncita de las Vegas mentioned by Cope; however, that drainageway was identified in the geologic study of the general district and is now shown on the new topographic sheet of the Gallina quadrangle by the U.S. Geological Survey.

As shown on the map, about five miles west of north of Gallina the base of the Wasatch formation swings away from the Cretaceous hog-backs forming the south boundary of the "extensive horseshoe" referred to in the quotation from Cope where he obtained many fossil remains of vertebrates. He mentions another horseshoe ten miles south of this also rich in fossil vertebrates; the southern area is about four miles north of what is now known as La Jara P.O. However, the horseshoe here is not formed by the extreme base of the Wasatch as is the case farther north. In the La Jara district the present writer obtained numerous vertebrate teeth and skeletal remains.

In the last paragraph of the above quotation of Cope's description, he states that the "Puerco marls" do not appear to represent the Fort Union or "Lignite beds of the North"; in writing later on the subject for the Geographical Survey west of the One Hundredth Meridian (*Annual Report* [1877], Part II, p. 18) he remarks that these beds "may represent the Fort Union or Lignite beds of the Upper Missouri some of whose strata they resemble in color and consistence." These remarks are noted with interest since recent explorations have shown that Torrejon fossils, which characterize the upper part of Cope's original Puerco, do occur in the Fort Union beds of Montana.[52, 68] Cope states that he did not succeed in obtaining fossil remains from the Puerco, other than petrified wood, and mentions finding numerous fragments of silicified limbs and trunks of dicotyledonous and palm trees, among them one stump which measured five feet in diameter. (See Fig. 7, this paper.) These remains are indeed abundant in this vicinity; on the summit of the mesa two miles west of Cuba post-office, which is the village Nacimiento, there are some ancient stone ruins which were built in large part of specimens of silicified wood.

Although Cope was unable to find satisfactory fossils in the Puerco at the time of its discovery in 1874, he obtained in 1880 the services of an experienced collector, David Baldwin, of Farmington, New Mexico, to make careful search for vertebrate remains in that formation. Baldwin collected with great success at intervals for several years, evidently finding the first Puerco fossils in the vicinity of Nacimiento and northward where the formation was known to Cope. More than ninety species of fossil mammals were sent from the Puerco which were described by Cope between 1881 and 1888 in numerous papers presented to the American Philosophical Society, Philadelphia Academy of Science, and the *American Naturalist.* These papers were devoted exclusively to descriptions of the fossils, with the exception of a brief note on "The Relation of the Puerco and Laramie Deposits" in the *American Geologist* for October, 1885, here quoted from as follows:

Some writers having suspected the identity of the formations above named, and the consequence which follows, that the Puerco mammalian fauna was contemporary with the dinosaurian fauna of the Laramie age, the following observations on their stratigraphic relations are now given. They are derived from the

notes of several years' residence and exploration by my correspondent, David Baldwin, which connect those made by myself in New Mexico in 1874, published in the Wheeler Survey report, with those made by Holmes and Endlich in 1878 in Colorado, and published in the Hayden Survey report.

At the locality where best developed, the Puerco beds have a thickness of about 850 feet, and contain Mammalia to the base (see *Naturalist* for April and May, 1885). The Laramie beds succeed downward, conformably it is thought by Mr. Baldwin, and have a thickness of 2,000 feet at Animas City, New Mexico. They rest on Fox Hills marine Cretaceous of less thickness. A few fossils sent from time to time by Mr. Baldwin identify the Laramie. This is especially done by the teeth of the dinosaurian genus *Dysganus* Cope, which is restricted to the Laramie formation everywhere. Also by the presence of the genera *Laelaps* and *Diclonius*, which in like manner do not extend upward into the Puerco beds. . . . .

It is thus evident that the Puerco formation is quite distinct from the Laramie, although it is possible that it may be proper to associate it with the Laramie in the post-Cretaceous series. When the Cretaceous mammalian fauna comes to be known, it will be very apt to agree with the Puerco in its leading features. These are the absence of Perissodactyla and of Rodentia, and of course of mammalian orders not found below the Miocenes; and in the constitution of the mammalian fauna by Condylarthra, Bunotheria and Marsupialia exclusively. The post-Cretaceous series as a whole may be ultimately distinguished from the Tertiary by these peculiarities, together with the presence of the reptilian genus *Champsosaurus*.[21]

Concerning the taxonomy of the original Puerco, Cope was at first inclined to place the beds in the Eocene because of their apparent conformability at the top with beds known to be of that age. He freely referred to the "Puerco Eocene" in his earlier papers but in 1885 receded from this opinion and, on the basis of the Mesozoic affinities of the fauna, placed the Puerco in what C. A. White had proposed to call the post-Cretaceous. This term has been used more or less to the present time as signifying a zone between the known Mesozoic and Cenozoic eras. But it is evident that Cope considered the Puerco fauna more closely related to the Cretaceous than to the Tertiary faunas as indicated in the following quotation from the *American Naturalist:*

The fauna of this horizon is well distinguished from that of the Laramie in the absence of the numerous Dinosauria of the latter, and the presence of numerous Placental Mammalia in the former. On these grounds I at first referred the formation to the Cenozoic series, but further reflection induced me to place it as now arranged. The reason is as follows: Although Placental Mammalia are not now known otherwise from Mesozoic beds, the other forms of the Puerco are especially Mesozoic in character. Such are the Choristodere Reptilia and

the Multituberculate Marsupialia, neither of which occur above, while both occur below the Puerco, the Multituberculata down to the Trias inclusive. Then the Placentialia are entirely peculiar in the absence of the Diplarthra and of the Rodentia, orders always found in the Cenozoic beds. Then the characters of the Condylarthra and Amblypoda and many of the Creodonta, which represent Tertiary types, are so peculiar that we are led to suspect that when the Cretacic Mammalia are fully known they cannot differ very widely from those of the Puerco.

But one area of this formation is definitely known; that is in Northwestern New Mexico and Southwestern Colorado. It consists of sandstones and soapy marls, and has a thickness of 850 feet. It is immediately overlaid by the Wasatch Eocene, and rests on the Laramie.[26]

In the writings of various paleontologists since the time of Cope, the Puerco has been placed provisionally in the lowermost Eocene, as will be referred to in further paragraphs.

The statement has been made in geologic literature from time to to time that the Puerco formation occurs in northwest New Mexico and southwest Colorado; but no beds known to be Puerco in age have yet been found in Colorado. This mistake arose from the work of Endlich in the San Juan region in 1875.[7] This was the year after Cope had discovered the formation at the head of the Puerco River in New Mexico to which he gave the name Puerco, and an attempt was made to correlate the beds on the opposite side of the San Juan Basin in New Mexico and Colorado. Holmes was working the same year along the La Plata and San Juan valleys west of Endlich. Both of these geologists described certain strata in their respective districts as "The Puerco Marls," basing the correlations entirely on lithologic similarity and stratigraphic position. It may be said in this connection that the term "marl," applied by Cope and others to these soft argillaceous and siliceous beds, was improper, since the term, though used loosely in the present day, necessarily implies strongly calcareous material.

At the time of the work of Endlich and Holmes and until the work of the writer in 1907,[70] it was not known that the Nacimiento group lies unconformably on the "Laramie" and is in turn overlain unconformably by younger formations. For this reason, it was naturally assumed by the geologists of that time that beds in the same basin lying next above the "Laramie" were Puerco in age. But the formation described by Endlich in Colorado[7] as Puerco is the Animas

formation described and named by Cross in 1892.[34] It is probable that the Puerco of Endlich included some of the lower members of the Wasatch which was determined in 1909 by J. W. Gidley and the writer to lie next above the Animas formation in this portion of the basin. The beds described by Holmes[8] as Puerco in his Pinyon Mesa section, about six miles north of the San Juan River and just west of the La Plata River in New Mexico, may be either Puerco or younger in age. He characterizes the formation as consisting of "soft sand, clays, and marls, highly colored with reds, yellows, and purples, growing gray below and containing masses of soft sandstone." This description agrees more closely with the Canyon Largo series of Newberry[1] than with the Puerco. Holmes correlates Newberry's Canyon Largo series with the Wasatch, which is probably correct, since the beds occupy the innermost portion of the San Juan Basin and could not well be older than Wasatch even though Newberry referred the whole series to the Cretaceous.

Besides the collections of David Baldwin made during the years 1881 to 1888 no contributions were made to the Puerco fauna until the year 1892. Baldwin died at his home in Farmington, New Mexico, several years ago, and thus was lost to science a valuable collector and with him much information never placed on record relative to the geographic locations of many fossil-bearing districts. His original collections which were described in numerous papers by Cope were purchased in 1895 by the American Museum of Natural History in New York City.

In 1892 and 1896 the American Museum of Natural History sent expeditions into the San Juan Basin for the purpose of further study of problems connected with the Puerco fauna. This work was under the direction of Dr. J. L. Wortman. As a result of these expeditions, a large amount of new material was obtained.

Some time after the first season's collecting by Wortman in 1892 a paper was written by Professor H. F. Osborn and Mr. Charles Earle entitled "Fossil Mammals of the Puerco Beds."[37] In this paper they quote the following field notes from Wortman:

> The thickness of the beds is roughly estimated at 800 to 1,000 feet, and as far as can be observed they lie conformably upon the Laramie. At no place examined by us can fossils be said to be abundant, but on the contrary most of the exposures are entirely barren. For convenience they are divided into Upper

and Lower Beds, but this scarcely gives an adequate idea of the occurrence of the fossils, for the reason that it is only the extreme upper and lower strata that are productive; the great intermediate part we found to be singularly barren.

The lower fossil-bearing strata occur in two layers, the lowermost of which lies with ten or fifteen feet of the base of the formation. This is succeeded after an interval of about thirty feet by a second stratum in which fossils are found, and this appeared to be by far the richer of the two. Both of these strata are of red clay, and at no place did we find them more than a few feet in thickness.

The lower horizon we found exposed in two places, viz.: the head of the Coal Creek or Pina Verta Cañon, and some of the upper tributaries of the Chaco Cañon. It is especially and sharply distinguished by the occurrence of the remains of *Polymastodon*, which appear to be entirely absent from the upper horizon.

Fossils are much more abundant in the upper strata, and wherever a good exposure was found their occurrence could be more confidently looked for. The genera *Chirox* and *Pantolambda* appear to belong exclusively to the upper beds. Owing to the widely separated localities and the general scarcity of fossils, it is at present impossible to say whether it is one or several layers that produce the fossils from these upper beds. It is my opinion, however, that there are several layers, and that their vertical range is somewhat greater than that of the lower horizon. The principal localities of the upper strata are as follows: head of Cañon Gallego, Cañon Blanco, Cañon Escavada, and head of Cañon Chaco.

It will be noted that near the beginning of the above quotation Wortman states that the Puerco beds "as far as can be observed lie conformably upon the Laramie." This statement is somewhat qualified perhaps, due to the uncertainty which necessarily arises from a study of formation contacts in undisturbed, unconsolidated deposits; it is especially difficult to recognize an unconformity in badland topography in the absence of abundant fossils and especially so without detailed, continuous mapping.

Wortman states that the two lower fossil zones lying within fifty feet of the base of the Puerco are characterized by the remains of *Polymastodon*, whereas the fossil zone near the top contains *Chirox* and *Pantolambda* which do not occur in the lower beds. In fact the faunas of the upper and lower beds of the original Puerco were found to be entirely distinct, which later led to the substitution of the name Torrejon formation for the upper strata and the restriction of the name Puerco formation to the lower beds.

HISTORY OF THE TORREJON

The possibility of distinction between the faunas of the upper and lower beds of the original Puerco had been noted by Cope. In his paper on the "Synopsis of the Vertebrate Fauna of the Puerco Series"[29] in 1888 he stated that the information at that time available indicated some faunal difference between the lower and upper beds. In bearing out this view he gave a list of twenty species peculiar to the lower beds, leaving to research to determine whether or not they occur also in the upper beds.

After the field expeditions of the American Museum of Natural History in 1892 and 1896, a systematic revision of the fauna from Cope's Puerco was taken up by Dr. W. D. Matthew, of that organization. In his paper of 1897 entitled "A Revision of the Puerco Fauna"[44] he emphasized the absolute distinctness in the faunas of the upper and lower beds, stating that they contain not a single species in common and that not a genus passes through without serious modifications of at least subgeneric value. The faunas were found to be as different as any other two successive Eocene formations, and it became necessary to adopt a new name to designate one of the two. It was then that Dr. Wortman proposed the name Torrejon formation for the upper beds, retaining the name Puerco for the lower. The name Torrejon was taken from the arroyo of that name in the type-locality. It has since been freely used and is firmly fixed in literature.

In 1901 Mr. Earl Douglass discovered Torrejon fossil vertebrates in Montana,[52] a fuller reference to which will be given under the head of "Correlations." With the exception of the one locality in Montana, no fossils have been found elsewhere in the United States corresponding to either of these unique faunas of the Nacimiento group of the San Juan Basin in New Mexico.

NAMING OF THE NACIMIENTO

In view of the fact that the Puerco was restricted to the lower formation when the name Torrejon was proposed, and since it is very necessary to adopt a group name in order to properly discuss the relationship of the two formations, the writer proposes the name Nacimiento group for the two formations used collectively. The rela-

tion of the group to the two formations here discussed is shown as follows:

Nacimiento group $\begin{cases} \text{Torrejon formation} \\ \text{Unconformity (?)} \\ \text{Puerco formation} \end{cases}$

This name is taken from the town by that name in the type-locality at the foot of the Nacimiento Mountains. Here Cope mentions the importance of the "Puerco," which he used to include everything between the "Laramie" and the Wasatch in this region.

GEOLOGY OF THE TYPE-LOCALITY

The following observations and conclusions, together with the map, are based on the writer's field work in the summer of 1907 under the supervision of Mr. M. R. Campbell. In the preparation of the map and securing of geologic notes, valuable assistance was received from Mr. William J. Reed (deceased) and Mr. Albert L. Beekly.

The results of this work were chiefly of value in that a map was prepared of the region westward from the Sierra Nacimiento and on this the geology was imposed. The unconformable relationship of the Nacimiento group was noted for the first time and something was learned of the physiographic record of the district in the late Cretaceous and early Tertiary. Unfortunately, the advantage was not at hand of having paleontologic determinations in the field in order to know what formations were being dealt with at that time. For instance, no distinction could be made in the lithologic character of the upper and lower beds of the Nacimiento group, the result being that the Puerco and Torrejon formations were not mapped separately. At the time of the field work, the writer had not had occasion to be familiar with the literature on the Puerco, Torrejon, and Wasatch of this field, and did not know the stratigraphic position at which fossil vertebrates had previously been found. The results in paleontologic collecting were, however, all that could be expected under the circumstances and were sufficient to make possible definite correlations.

The region under discussion is one of little culture and sparse population. Gallina is a small Mexican settlement of about 100 people, located at the point where Gallina River emerges from the Sierra Nacimiento. About 14½ miles south-southwest is the old

Mexican town of Nacimiento, known to the postal officials as Cuba. This village contains about 200 inhabitants, and is located in a small fertile valley at the foot of San Pedro Mountain, near the point where Nacimiento Creek joins Rio Puerco. La Jara, Copper City, and Señorito are settlements of less importance. About thirty-four miles south of west from Cuba is Raton Spring, where there are two Mexican stores and a few dwelling-houses. Raton Spring is known also as Pueblo Pintado, a name formerly applied to the Aztec ruins, which are still evident at this place. The spring itself is a deep pool of some-

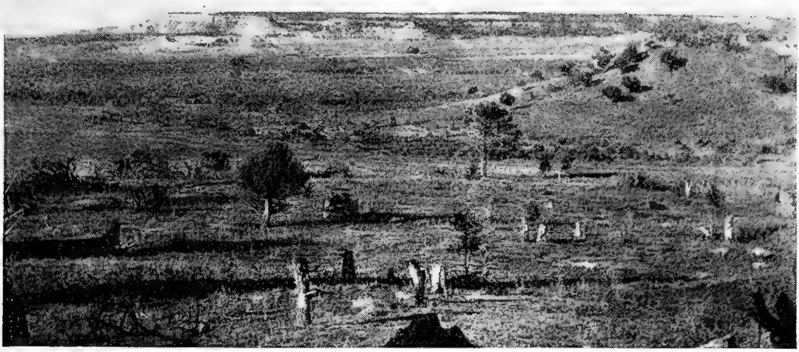

FIG. 2.—Puerco formation, ten miles west of south of Nacimiento, New Mexico

what alkaline water, which flows as a mere seep. At Ensina Spring, between Cuba and Raton, eleven miles north of east from Raton there are some Indian stone huts, but the spring is known as a watering-place for miles over the surrounding desert country. The water issues from beneath a massive sandstone, and the flow in August, 1907, was about one gallon per minute. These are the only localities worthy of individual mention here, but there are numerous Mexican ranches along the west foot of the Sierra Nacimiento between Gallina and Cuba.

On the west the Sierra Nacimiento presents a bold front, and along its slopes the sedimentary rocks are steeply inclined and

form hog-backs. At some places the slopes are extensively covered by bowlders and wash, principally granite and granite porphyry from the mountain mass. The broad plateau country, stretching westward to San Juan River, is a dry, barren expanse of highly colored mesas and badlands, known as the Nacimiento Desert.

The following generalized section presents the stratigraphic

FIG. 3.—Silicified stump in Puerco formation, near Encina Spring, New Mexico

relationship of the Nacimiento group in the region of the Puerco River:

GENERALIZED SECTION OF ROCKS IN THE PUERCO REGION

System	Series	Group or Formation	Thickness in Feet
Quaternary	Pleistocene	Recent terraces, etc.	0–50
Tertiary	Eocene	Wasatch formation (Unconformity)	1,000
		Nacimiento group (Unconformity): Torrejon formation	275
		(Unconformity ?)	
		Puerco formation	560
Cretaceous	Upper Cretaceous	"Laramie" formation	900
		Lewis shale	500
		Mesaverde formation	400
		Mancos shale	1,000
		Dakota sandstone	300

The character of individual strata composing the two formations of the Nacimiento group may be gathered from the following section along the west side of the Puerco River below Nacimiento:

SECTION OF NACIMIENTO GROUP ALONG PUERCO RIVER SOUTH AND WEST OF NACIMIENTO

		Thickness in Feet	
(Wasatch formation)			
(Unconformity)			
Torrejon	Shale, variegated	20	
	Sandstone, brown	3	
	Shale, gray	15	
	Sandstone, gray	3	
	Shale, gray and soft sandstone	40	
	Sandstone, massive, tan-colored	15	
	Shale, yellowish	15	
	Sandstone, massive, soft, coarse, tan-colored	120	
	Shale, gray	20	
	Sandstone, massive, soft, tan-colored	30	
(Unconformity)	Thickness of Torrejon formation		276
Puerco	Shale and soft sandstone	30	
	Shale, dark, carbonaceous	10	
	Shale, gray	10	
	Sandstone, massive, yellowish, lenticular	10	
	Shale, variegated	25	
	Shale, dark carbonaceous	4	
	Shale, chiefly yellowish	80	
	Sandstone, massive, brown, lenticular	10	
	Shale, variegated and soft, gray sandstone	200	
	Sandstone, massive, coarse-grained, brown	40	
	Shale, gray and soft sandstone	45	
	Shale, very dark, local coal streaks	4	
	Shale and soft sandstone of gray and tan colors	90	
(Unconformity)	Thickness of Puerco formation		558
(Lewis shale)	Thickness of Nacimiento group		834

The section given above may be taken as typical for the beds of the Nacimiento group in the type-locality. The total thickness of either the Puerco or Torrejon is variable owing to the unconformities that limit each of these formations at the top. This limitation in thickness is brought about by erosion and removal of rocks during the time-interval after the close of each formation.

The Puerco and Torrejon formations are not sufficiently contrasted lithologically to permit of their being readily separated at all points without fossil evidence. Along the Puerco River, where erosion has removed the greatest amount of material the stratigraphic succession is more clearly exposed than at any other point within the area. Here the entire group, with a total thickness of about 835 feet, forms prominent escarpments, mesas, and badlands along a wide belt between the outcrops of the "Laramie" and the Wasatch.

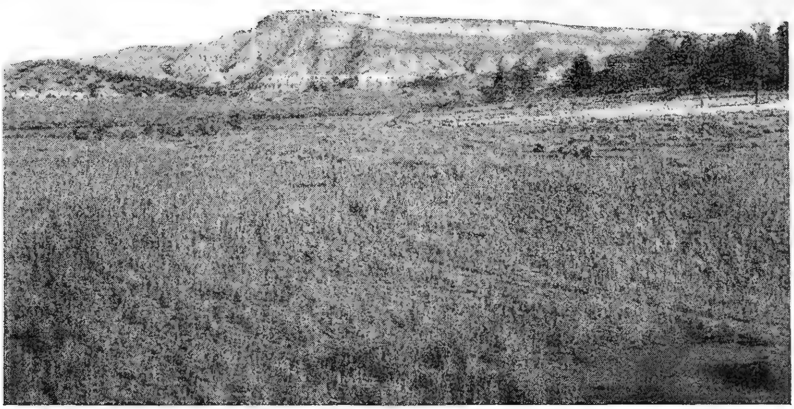

FIG. 4.—Torrejon formation, eight miles northeast of Encina Spring, New Mexico; showing one of the natural monuments from which the Arroyo Torrejon takes its name.

In this vicinity, the Puerco formation is characterized to some degree by the presence of dark to black layers of carbonaceous shale. At a point about three miles north of east of Nacimiento and at about the same horizon, near the base of the formation eleven miles west of south of the same town, there are local thin lenses of coal in the Puerco formation. In the Torrejon formation northeast of Encina Spring, where fossil mammals were found, thus enabling positive identification of those beds, there are occasional, lenticular layers of dark

carbonaceous shale very similar to the dark layers in the underlying Puerco; but on the Puerco River the carbonaceous layers are confined to the Puerco formation almost entirely.

Both the formations of the Nacimiento group consist essentially of variegated clay shale, arenaceous shale, and soft, coarse-grained sandstone of white, gray, and tan colors. Such beds are of that consistency necessary to the development of badland topography, with the exception of local, siliceous sandstones hard enough to form mesas or dip slopes through which intermittent streams cut canyons into the underlying shale. The latter is more particularly the type of topography in the vicinity of Nacimiento. The softer sandstones which commonly alternate with the arenaceous and clay shale usually weather to soft incoherent sand at the outcrop. These beds have been said to consist in part of unconsolidated sand but the writer has found the term applicable only to weathered exposures; for in every case the sand is solid at a short distance from the surface.

There are local conglomerate layers in both the Puerco and Torrejon but they are of minor importance and exceptional. No one member of either of the formations is a true conglomerate such as the basal conglomerate of the Wasatch formation. However, occasional lenses of small quartz and chert pebbles are to be seen in the more massive, coarse-grained, siliceous sandstones.

The basal sandstone of the Wasatch is strongly conglomeratic, consisting of pebbles averaging the size of an egg and of varied composition; the pebbles consist of quartz and chert, of red, black, brown, and white colors, and various crystalline rocks. The matrix is composed chiefly of coarse, brown quartz grains. This sandstone is a prominent horizon-marker over a wide area on the south and east sides of the San Juan Basin. On the north side of the basin, in southwest Colorado, where the Wasatch rests on the Animas formation, this conglomerate member is absent.

With the exception of the conglomerate above mentioned the formations of the Nacimiento group are lithologically distinguished only in a slight degree from the overlying Wasatch. The Wasatch contains a larger percentage of highly colored shales and softer sandstones than the Nacimiento, but otherwise the composition is not materially different. The contrast of the Nacimiento group with the "Laramie"

of this basin is more marked since the latter consists largely of massive brown sandstones alternating with drab, clay, and arenaceous shale together with local carbonaceous shale and coal beds.

The structure in the area under discussion, with the exception of unconformable relationships in strata, is such as is common around the margins of most of the minor basins in the Rocky Mountain province. Steeply inclined strata limit the older sedimentary rocks along the boundary of the Nacimiento Mountains, the dips decreasing westward toward the interior of the San Juan Basin. (See

FIG. 5.—Upper escarpment of Nacimiento group, four miles southwest of Nacimiento, New Mexico.

sketch map, Fig. 1.) Near the mountains, this inclination varies from 35° north of Gallina to more than 90° at Copper City and northward. In the latter district, the fold is overturned and dips 70° eastward toward the mountains. All the sedimentary formations above the Jurassic have this inclination with the exception of the Wasatch. About ten miles northwest of Gallina the Wasatch has an inclination of about 10° west of south as mentioned by Cope[5] and verified by the writer. The dip in that vicinity is apparently local and is of more recent date than any uplift in the Nacimiento Mountains as shown by the fact that the Wasatch beds rest nearly horizontally against the crystalline rocks of those mountains between Gallina and Nacimiento.

Along the Arroyo Torrejon, the Cretaceous and Tertiary formations are very slightly disturbed; the dips in this region are probably initial slopes with the exception of local variations produced by settling of the strata; the latter are noticeable in the Torrejon beds on the east fork of the Arroyo Torrejon near the Escavada road.

The Nacimiento group is limited by very evident unconformities at the top and bottom as shown on the accompanying map. The more evident of these two unconformities is the one at the top, or at the base of the Wasatch formation. Between Gallina and Nacimiento the Wasatch covers the outcrops of sedimentary rocks, including the Nacimiento, "Laramie," Lewis, Mesaverde, Mancos, Dakota, and older formations. Four miles northeast of Nacimiento, where the Wasatch covers the upturned edges of older rocks, and from there northward along the foot of the mountains, the unconformable relationships are strikingly shown. This overlap of the Wasatch on older beds is equally evident four miles northwest of Gallina, where the soft, variegated shales swing across nearly to the Mesaverde hog-back. This unconformity at the base of the Wasatch is not easily recognized away from the mountains. The contact with the underlying formation of the Nacimiento group on the Arroyo Torrejon would not ordinarily be considered unconformable; for there is no discordance in dip in that section and there is no contrast in either composition or color of the sediments on either side of the contact. The variegated shale and soft sandstone of the Torrejon and Wasatch on respective sides of the unconformity are very similar. These facts, together with the variability in color and lenticular character of deposits in each of the formations, make this unconformity very difficult of detection except where the stratigraphic break is recorded in the dynamic structure. The same holds true for the unconformity at the base of the Puerco.

The unconformity at the base of the Puerco formation is evident at the point eleven miles southwest of Nacimiento, where the "Laramie" sandstone, shale, and accompanying coal beds appear from beneath the Puerco striking nearly at right angles with it. Westward from this locality, where the outcrops are nearly parallel and there is no inconsistency in direction of dip, the unconformity is not so easily noted.

The hiatus between the "Laramie" and the Puerco apparently does not represent so great a time-interval as that between the Torrejon and the Wasatch. The indications are that the unconformity at the base of the Puerco is in part one of overlap. The angularity is slight between it and the underlying "Laramie" and Lewis shale. However, the direction of strike at the point of overlap is not the same as in the lower formation, which fact probably indicates a slight folding of the Cretaceous rocks and subsequent erosion previous to the deposition of the Puerco formation. On the other hand, the

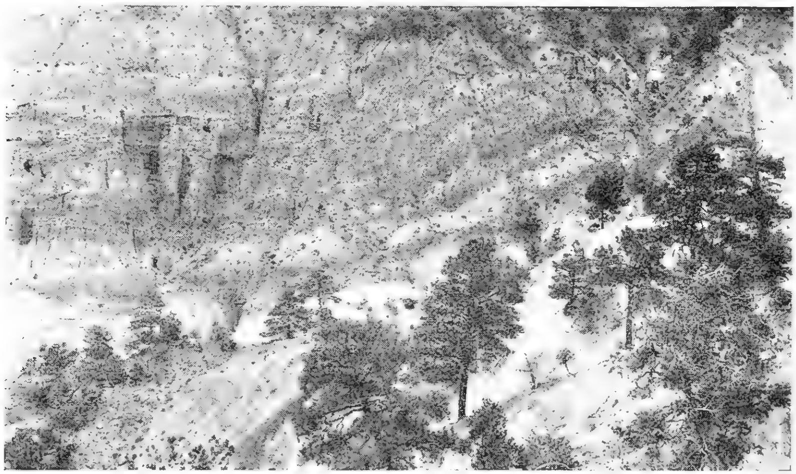

FIG. 6.—Shale of the Nacimiento group, three miles northeast of Nacimiento, New Mexico. Tilted to vertical by uplift of the Nacimiento Mountains.

break at the base of the Wasatch is represented by a very strong angular unconformity indicating a long period of erosion previous to its deposition, after the close of the Torrejon.

The unconformity between the Puerco and Torrejon formations cannot be noted in the field except on fossil evidence. It is highly probable that it is one essentially of overlap with very little stratigraphic break. The two formations are so closely similar in lithologic character that it is difficult to distinguish one from the other without the assistance of fossils. For this reason, the two could not be indicated separately in the brief season spent in the preparation of data for the accompanying map. However, the base of the Torrejon is

known at certain points and the inconstant thickness of the interval between this horizon and the base of the Puerco indicates the unconformable relationships between the two formations. For instance, on the Rio Puerco and at other points where the full section of the Nacimiento group is represented, the Torrejon formation is more than 500 feet stratigraphically above the base of the Puerco. From the Rio Puerco, where the full section of the group is present, the base of the Puerco formation was traced westward very definitely to the Arroyo Torrejon. In the latter district some of the upper members of the Puerco are notably absent and the Torrejon fossil mammals were secured at a little over 200 feet above the base of the Puerco, thus indicating an unconformity at that point unless a very notable thinning takes place in only the upper member of the Puerco. Since the members in the lower portion of the Puerco are persistent across the area and since the vertical distance between the base of the Puerco and the base of the Torrejon is scarcely sufficient to represent the great time-interval indicated by the evolution of the Torrejon fauna, it seems highly probable that the Torrejon is unconformable here. The stratigraphic section as prepared on the east fork of the Arroyo Torrejon is given below:

SECTION OF THE NACIMIENTO GROUP ON THE EAST FORK OF ARROYO TORREJON, FOUR MILES EAST OF THE FARMINGTON ROAD

		Thickness in Feet	
(Wasatch, massive, conglomeratic sandstone at base)			
(Unconformity)			
Torrejon	Shale, drab and gray	14	
	Shale, dark, carbonaceous and thin sandstone	20	
	Sandstone, soft, gray and reddish shale	16	
	Shale, black, yellow, drab, and gray	35	
	Sandstone, soft, tan-colored	20	
	Shale, gray, strongly arenaceous (fossil mammals)	35	
(Unconformity ?)	Thickness of formation		140
Puerco	Shale and soft sandstone	100	
	Sandstone, massive, coarse-grained, tan-colored	30	
	Shale, red, purple, drab, and white	30	
	Shale, sandy, gray, dark, and yellowish	50	
(Unconformity)	Thickness of formation		210
"Laramie," sandstone, massive, brown	Thickness of group		350

The third member above the base of the Puerco in the above section is a very persistent horizon-marker and corresponds to the fourth member above the base of the Puerco in the section previously given along the Puerco River; this member was traced continuously from the Nacimiento Mountains to beyond the Arroyo Torrejon.

The sedimentary record as preserved in the strata of the Nacimiento group is capable of slight variance of interpretation in respect

FIG. 7.—Shale of the Nacimiento group, three miles northeast of Nacimiento, New Mexico. Short distance west of the preceding view.

to origin. It is evident, however, that they were deposited in fresh water as shown by both the lithologic composition and the fossils. The beds may be largely the result of accumulation of sediment on the floor of an extensive fresh-water lake with alternate flooding and withdrawal of water, or they may have resulted chiefly from confluent alluvial fans along broad streams; or more probably the physiography involved a combination of the two conditions.

There is a notable absence of chemical deposits in the formations

under discussion except those resulting from secondary deposition or weathering. There are occasional concretions of barite observed by the writer in the Torrejon shale ten miles northeast of Encina Spring, which may be nearly contemporaneous with the rocks which inclose them. These are rough, irregular-shaped, often discoidal aggregations of impure barium sulphate; they lie imbedded in clay shale with which they harmonize closely in color, being usually dark gray with a slightly bluish tinge. It is quite possible that they represent the segregation of this slightly soluble salt at the time of deposition or while the shale was in a semiplastic state. Neither the Puerco nor Torrejon, so far as known, contains any primary deposits of salt, gypsum, or limestone; rarely there are present thin lenses of dark-colored limonite.

The beds of the Nacimiento group show evidences of the existence of currents from time to time during their deposition. Thin layers of small quartz pebbles and cross-bedding are not uncommon. The sudden termination along the bedding of massive sandstones is quite common and in the absence of faults can scarcely be accounted for except by the effects of stream-channels. The presence of smooth, globular forms of siliceous sandstone within sandstone of a similar matrix may be accounted for by either concretionary forces or by the action of currents. The variegated shale layers common to the upper beds and the overlying Wasatch formation probably represent varying degrees of oxidation at or near the surface during deposition.

It is the writer's opinion that the materials of the Nacimiento group in this region were transported by broad, shallow streams and laid down in deltas, lagoons, and shallow fresh-water lakes over a broad peneplaned surface. At the close of the Cretaceous, this portion of the continent was possibly slightly above sea-level, the elevation having been gradual from the time of marine deposition of the Lewis shale on through a time of brackish and fresh-water accumulation to land conditions at the close of the "Laramie." There was then a period of widespread orogenic movement, mountain growth, and attendant structure, accompanied and followed by erosion and accumulation of local, fresh-water sediments; at this time the formations of the Shoshone group, including the Arapahoe and Denver formations, of the Denver Basin, and the Animas formation of the

San Juan Basin were deposited. The uplift in the San Juan Mountains of southwestern Colorado at the close of the "Laramie" folded the Cretaceous sediments steeply along its flanks, but at some distance from them the sedimentary rocks were only slightly disturbed and possibly at no great elevation above tide. While local deposition was in process at this time in certain regions near the mountains, the elevated sedimentaries over other, perhaps extensive, areas were

FIG. 8.—Shale in the Wasatch formation, six miles southwest of Gallina, New Mexico, similar in appearance to the Nacimiento, but usually more highly variegated.

being reduced to base-level. By the beginning of Puerco time an extensive gently sloping plane had been produced over which broad streams flowed quietly to the sea, depositing sediment in shallow lakes and lagoons along their courses and at times shifting in position or overflowing and commingling with each other. Such a theory seems to explain the nature of the deposits as well as the conditions suitable to the fauna. In order to account for the thickness of the sediments deposited in this manner it seems necessary to assume that a slow submergence of the land kept equal pace with deposition.

The Nacimiento beds probably once extended far beyond the present confines of the Eocene in the San Juan Basin; possibly southward toward the Gulf of Mexico and westward into Arizona and Utah. The beds are confined to this basin at present because it owes its origin to structure which was produced certainly in part, and perhaps largely, after the close of Nacimiento time. Subsequent erosion has removed the formations of this group probably over extensive bordering regions while within the basin they are preserved by a thick covering of Wasatch. The Nacimiento Mountains, which limit the basin on the east, were surely elevated after the close of Nacimiento time, since the strata of that group are tilted at high angles and even overturned along its flanks. These mountains are of laccolithic origin and both the Puerco and Torrejon undoubtedly at one time continued beyond them.

FOSSILS

The fossils thus far found in the beds of the Nacimiento group by Baldwin and subsequent collectors are chiefly vertebrates and in a large measure representatives of the Mammalia. There are several genera and species among the Reptilia and fragments of bones of undetermined specimens of Aves. Of the Mollusca, four fresh-water forms from the Puerco, near the town of Nacimiento, were sent to Cope and described by Dr. C. A. White in 1886.[23] Among these forms, White doubtfully determined one species as *Unio rectoides* which he had found in the base of the Wasatch near Wales, Utah. Unfortunately the Nacimiento has furnished no fossil leaves, the only indications of flora being found in the form of silicified limbs, trunks, and stumps of dicotyledonous and palm trees.

The following remarks relative to the fossil mammals of the Nacimiento group are quoted from Professor H. F. Osborn:[65]

POLYMASTODON ZONE (PUERCO FORMATION)

Small archaic mammals evolving from Cretaceous, Jurassic, and Triassic ancestors. Multituberculata, which originated in the Triassic, 3 families. Two orders of archaic ungulates—(1) Amblyopoda-Periptychidae, (2) Condylarthra-Phenacodontidae. Archaic Carnivora-Creodonta, 3 families: (1) Oxyclaenidae, (2) Mesonychidae-Triisodontinae, (3) Arctocyonidae (*Claenodon protogonoides*). Edentata-Taeniodonta, with enameled teeth, 2 families: (1) Stylinodontidae, (2) Conoryetidae.

SUMMARY OF GENERA AND SPECIES

	Genera	Species
Archaic Triassic mammals	3	5
Archaic Cretaceous mammals	15	24
Total archaic mammals	18	29
Modernized or distinctively Tertiary mammals	0	0

The Puerco is a fauna wholly of Mesozoic origin, and mostly destined to disappear; not a single representative or ancestor of any existing order of Tertiary mammals is certainly known. Cope's opinion that many of these mammals were ancestral to the modernized mammals lacks direct confirmation at present. Other paleontologists, however, are inclined to connect certain of the creodont families with the modern Carnivora. These and other ancestral connections may be demonstrated in the future.

Negatively, therefore, the Puerco is distinguished by the absence of primates, rodents, true carnivores, specialized insectivores, artiodactyls, perissodactyls, etc. This generalization has hardly less important bearings on paleogeography than on paleozoölogy.

PANTOLAMBDA ZONE (TORREJON FORMATION)

Like the Puerco this is almost exclusively a Mesozoic fauna, destined to become extinct during the Eocene. The known exceptions in surviving types are the pro-Carnivora-Miacidae, which first appear at this stage. Others will be discovered.

Mammals of larger size, mostly evolved from the Puerco mammals. Last survivors of the Multituberculata. Edentata-Taeniodonta of larger size. Of archaic Ungulata, 2 orders and 3 families: (1) Condylarthra-Phenacodontidae, (2) Amblypoda-Periptychidae, (3) Amblypoda-Pantolambdidae. Of the latter, *Pantolambda* is supposed to be ancestral to the Coryphodontidae of the Wasatch. Carnivora-Creodonta, 4 families: (1) Mesonychidae, (4) pro-Carnivora-Miacidae. The primate-like *Indrodon* and aberrant *Mixodectes* are of unknown relationships; they are possibly Insectivora.

SUMMARY OF GENERA AND SPECIES

	Genera	Species
Archaic Triassic stock	3	4
Archaic Cretaceous stock	21	36
Total archaic stock	24	40
Modernized Tertiary stock	1	1

LIST OF FOSSILS FOUND IN THE PUERCO AND TORREJON FORMATIONS

Mammalia*

Puerco
Polymastodon zone
1. San Juan Basin, New Mexico

Torrejon
Pantolambda zone
1. San Juan Basin, New Mexico
2. Fort Union formation (in part), Montana

Puerco	1	Torrejon	1	2
MULTITUBERCULATA				
Plagiaulacidae				
Neoplagiaulax americanus Cope...	×	*Neoplagiaulax molestus* Cope...	×	
Catopsalis foliatus Cope..........	×	*Ptilodus mediaevus* Cope.......	×	
Polymastodon taoensis Cope.......	×	*Ptilodus trovessartianus* Cope...	×	
Polymastodon attenuatus Cope.....	×	*Ptilodus plicatus* Cope.........	×	
Polymastodon selenodus O. and E..	×	*Ptilodus montanus* Douglass....		×
		Ptilodus gracilis Gidley........		×
		Polymastodon fissidens Cope....	?	
CREODONTA				
Miacidae				
		Didymictis haydenianus Cope...	×	
Arctocyonidae				
		Claenodon corrugatus (Cope)...	×	
(?)		*Claenodon ferox* (Cope)........	×	
		?Claenodon protogonioides (Cope)....................	×	
Mesonychidae				
		Dissacus navajovius Cope......	×	
		Dissacus saurognathus Wortman	×	
Triisodontidae				
Triisodon quivirensis Cope	×	*Sarcothraustes antiquus* Cope....	×	
Triisodon heilprinianus Cope......	×	*Goniacodon levisanus* Cope.....	×	
Triisodon guadrianus Cope.......	×	*Microclaenodon assurgens* Cope..	×	
Oxyclaenidae				
Oxyclaenus cuspidatus Cope.......	×	*Chriacus pelvidens* (Cope)......	×	
Oxyclaenus simplex (Cope).......	×	*Chriacus baldwini* Cope........	×	
Loxolophus hyattianus (Cope).....	×	*Chriacus truncatus* Cope.......	×	
Loxolophus priscus (Cope)........	×	*Chriacus schlosserianus* Cope...	×	
Loxolophus attenuatus O. and E...	×	*Tricentes subtrigonus* (Cope)....	×	
Carcinodon filholianus (Cope).....	×	*Tricentes crassicollidens* Cope...	×	
Paradoxodon rutimeyeranus (Cope)	×	*Deltatherium fundaminis* Cope.	×	

* The arrangement of the list of mammals is that of Dr. W. D. Matthew. See bibliography, No. 65.

		INSECTIVORA		
		?Hyopsodontidae		
Mioclaenus turgidunculus Cope....	×	*Mioclaenus turgidus* Cope......	×	
		Mioclaenus lemuroides Matthew	×	
		Mioclaenus acolytus Cope......	×	×
		Mioclaenus lydekkerianus Cope.	×	
		Mioclaenus inaequidens (Cope).	×	
		?Protoselene opisthacus (Cope).	×	
		Incertae sedis		
Oxyacodon apiculatus O. and E....	×			
Oxyacodon agapetillus (Cope).......	×			
		Pantolestidae		
		Pentacodon inversus Cope......	×	
		Mixodectidae		
		Mixodectes pungens Cope......	×	
		Mixodectes crassiusculus (Cope)	×	
		Indrodon malaris Cope........	×	
		TAENIODONTA		
		Stylinodontidae		
Wortmania otariidens Cope.........	×	*Psittacotherium multifragum* Cope.....................	×	
		Conoryctidae		
Onychodectes tisonensis Cope......	×	*Conoryctes comma* Cope........	×	
Onychodectes rarus O. and E......	×			
		CONDYLARTHRA		
		Phenacodontidae		
?Protogonodon pentacus Cope.....	×	*Tetraclaenodon puercensis* (Cope)...................	×	×
?Protogonodon stenognathus Matthew.....................	×	*Tetraclaenodon minor* (Matthew)	×	×
		AMBLYPODA		
		Periptychidae		
Periptychus coarctatus Cope.......	×	*Periptychus carinidens* Cope....	×	
Ectoconus ditrigonus (Cope).......	×	*Periptychus rhabdodon* (Cope)..	×	
Conacodon entoconus (Cope).......	×	*Haploconus lineatus* Cope......	×	
Conacodon cophater (Cope)........	×	*Haploconus corniculatus* Cope..	×	
Anisonchus gillianus Cope........	×	*Anisonchus sectorius* Cope.....	×	
Hemithlaeus kowalevskianus Cope..	×			
		Pantolambdidae		
		Pantolambda bathmodon Cope..	×	
		Pantolambda cavirictus Cope...	×	×

The following fossils other than mammalia have been found in beds of the Nacimiento group in New Mexico:

Reptilia

CROCODILIA

Several new undescribed species

TESTUDINATA

Conchochelys admirabilis Hay (Nacimiento)
Plastomenus acupictus Hay (Torrejon)
Aspideretes singularis Hay (Torrejon)
Platypeltis antiqua Hay (Torrejon)
Plastomenus? communis Cope
Chelydra crassa Cope
Dermatemys sp.
Compsemys sp.
Emys sp.

RHYNCOCEPHALIA

Champsosaurus australis Cope
Champsosaurus puercensis Cope
Champsosaurus saponensis Cope

OPHIDIA

Helagras prisciformis Cope

Aves

Fragments of bones of undetermined species

Mollusca

Helix nacimientensis
Helix adipis
Pupa leidyi (?)
Unio rectoides (?)

Flora

Wood of dicotyledonous and palm trees, undetermined

The fossil mammal teeth shown in Fig. 9 were collected by the writer in 1907 from the Torrejon formation eight miles northeast of Encina Spring, New Mexico (see Plate I). These fossils are in the hands of Mr. James W. Gidley, custodian of fossil mammals in the National Museum. He furnishes the following identifications of them which are subject to correction. There are new genera and species represented which will be described fully in a forthcoming paper by Mr. Gidley.

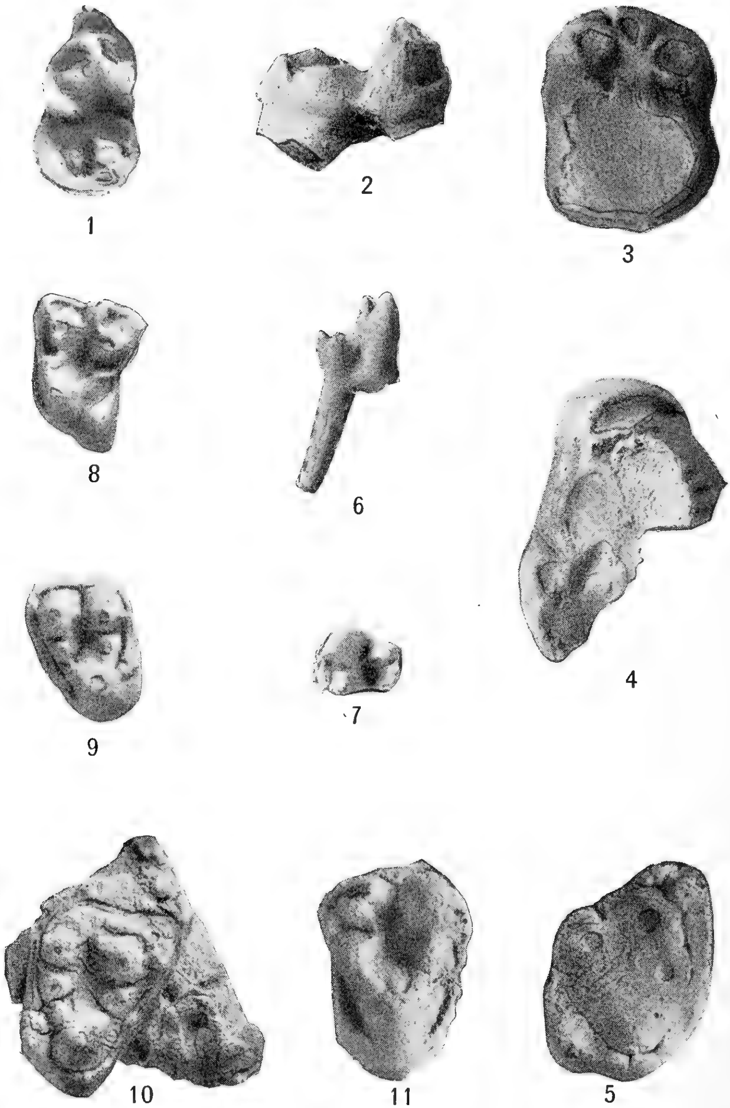

FIG. 9.—Fossil mammal teeth from the Torrejon formation, magnified 3 diameters, except No. 9, which is 4 diameters.

No. 1. *Chriacus plevidens* (Cope), last right lower molar, crown view. Accession No. 5713.

No. 2. Same as No. 1 (side view).

No. 3. *Periptychus carnidens,* left lower molar, m_2, crown view. Accession No. 5707.

No. 4. *Periptychus carnidens,* right lower premolar, ? p_3, crown view. Same individual as No. 3.

No. 5. *Euprotogonia puercensis,* last right upper molar, crown view. Accession No. 5710.

No. 6. *Insectivor,* new genus and species, right lower molar, ? m_2, side view. Accession No. 5715.

No. 7. Same as No. 6, crown view.

No. 8. *Olbodotes ? copei,* second upper molar of left side, crown view. Accession No. 5714.

No. 9. *Oxyclaenus* sp., second upper molar of left side crown view. Four times natural size.

No. 10. *Tricentes subtrigonus,* second upper molar of right side in fragment of jaw, crown view. Accession No. 5709.

No. 11. *Miacidae,* genus and species new, second upper molar of right side, crown view. Accession No. 5712.

CORRELATIONS

With the exception of a small area in Montana where Torrejon fossils have been found, neither of the faunas of the Nacimiento group is known in North America outside of the one limited region in the San Juan Basin of northwestern New Mexico.

The beds in Montana which contain the Torrejon fossils were discovered by Mr. Earl Douglass in 1901.[52] The first fossils were found near Fish Creek in Sweetgrass County, T. 6 N., R. 16 E., in beds of Fort Union age. A collection of leaves from a sandstone overlying the shale containing Torrejon vertebrates was sent to Dr. F. H. Knowlton who pronounced the species all Fort Union beyond a doubt. In 1908 and 1909 collections for the U.S. National Museum were made in this region by Messrs. A. C. Silberling and J. W. Gidley. All who have worked in the district agree that the fossils are in the Fort Union and all who have studied the fauna, including Scott, Matthew, Gidley, Farr, and Douglass, agree that the fossils are Torrejon. In that region beneath the Fort Union, containing the fossil mammals, is the Lance formation or "Ceratops beds." This formation contains dinosaurs and is Cretaceous in age, unless perchance dinosaurs lived into Tertiary time as the flora seems to

indicate. The evidence as to the age of these beds is conflicting when viewed from different paleontological standpoints, and has led to an interesting discussion by Stanton[69] and Knowlton.[68] But so far no fossils of the lower formation of the Nacimiento group, or Puerco, have been found in Montana. It is quite possible that they may be discovered later either in lower beds of the Fort Union or in the underlying Lance formation.

There is one locality on the south side of the San Juan Basin, namely at Ojo Alamo (see Plate II), where the writer obtained dinosaurs from beds unconformably above the "Laramie" and below the Wasatch. Mr. C. W. Gilmore of the U.S. National Museum reports that they appear to represent a typical fauna of the "Ceratops beds." The beds at Ojo Alamo have been searched in vain for fossil mammals and have furnished several new species of fossil turtles, but the fact remains that so far they have not been correlated with any other formation of that basin. They are very similar in appearance to the beds of the Nacimiento group, are only a short distance west of the Puerco region, and occupy the interval between the "Laramie" and Wasatch. Their definite relation to the Nacimiento group must be left for future elucidation.

There are two foreign countries where faunas closely related to those of the Nacimiento group have been found, one in Europe, the other in South America.

The Thanetien, or Cernaysien, of France, corresponds broadly with the Puerco and Torrejon.[32, 48, 65] As pointed out by Osborn,[65] the fauna of the "Conglomerat de Cernay" near Rheims shows a homotaxis with that of the Torrejon by similar stages of evolution in the representatives of three families, namely, (1) Plagiaulacidae, (2) Arctocyonidae, and (3) Mesonychidae-Triisodontidae. Other identifications are very uncertain.[32] Professor Charles Depéret, of the University of Lyons, correlates the beds of Cernay with those near La Fère, Rilly, Châlons-sur-Vesle, in France, and the Erguelines in Belgium.

In South America, the basal Eocene or Notostylops beds of Patagonia contain fossil mammals similar to those of the Puerco formation,[65] thus probably indicating a contemporary or previous land connection between the two Americas.

SUMMARY

The beds comprising the Nacimiento group were discovered by Professor E. D. Cope[5] in 1874 on the head drainage of the Puerco River in the San Juan Basin, northwest New Mexico. In 1875, these beds were thought to have been identified on the opposite side of the basin in New Mexico by Dr. W. H. Holmes.[8] The same year Dr. F. M. Endlich[7] working in the San Juan Basin north of the New Mexico boundary line correlated with the Puerco a series of beds along the Animas River in southwest Colorado. These correlations of the Puerco by Holmes and Endlich were based entirely on lithologic resemblance and stratigraphic position. The beds spoken of by Holmes[8] in his Pinyon Mesa section may be either Puerco or younger, while the beds described by Endlich[7] and shown on Hayden's Preliminary Map of Central Colorado are now known by the writer to be identical in larger part with the Animas formation of Dr. Whitman Cross.[34]

The name Torrejon was proposed by Dr. J. L. Wortman in 1897 [42] for those beds previously known as the upper part of the Puerco, but which contain species of fossil vertebrates totally different from those of the lower beds, subsequently known as Puerco proper. The discovery of the Torrejon fauna was due to Dr. Wortman's observations in the field in 1892 [37] together with paleontologic records kept by the American Museum of Natural History.

The Puerco and Torrejon formations have not been identified over wide areas. All the fossils collected from these formations came from limited districts in northwest New Mexico until recent years. Neither of the two formations had been positively identified beyond this region, nor similar fossils found elsewhere, until 1901. That year Mr. Earl Douglass[52] discovered Torrejon vertebrates near Fish Creek of the Musselshell River, Montana. The U.S. National Museum has since made extensive collections of these fossils, but no typical Puerco fauna has yet been discovered in North America outside of the San Juan Basin in northwest New Mexico. As has already been set forth, the "Laramie" and the Nacimiento of the San Juan Basin were each followed by a stratigraphic break, involving a considerable erosion-interval and marked faunal change. An unconformity of less importance separates the two formations of

the Nacimiento group. Unfortunately, no flora has been discovered from either of these formations. The great break in the character of the fossil vertebrates in passing from one formation to the other, or to the underlying "Laramie" and overlying Wasatch, has long been a puzzle. The beds were thought by Cope to lie conformably on the "Laramie" and in turn to be overlain conformably by the Wasatch. This idea was borne out by later authors on the subject and collectors in the field. Not until the work of the writer in 1907, however, had there been any attempt at mapping the formations. It was in connection with tracing the formation boundaries and a study of the physiographic record that the unconformities became evident. Lithologically the Torrejon is not sufficiently distinct from the Puerco to permit of its being readily mapped in the field, the separation being made on fossil evidence.

In this paper the topography, structure, stratigraphy, and physiographic record of the Puerco district have been described for the first time with the exception of a brief reference by the writer in one of the bulletins of the U.S. Geological Survey.[70]

The faunas of the Nacimiento group are unique. The upper fauna, the Torrejon, is known in only one limited area of North America outside of the type-locality. This is east of the Crazy Mountains in Montana. The lower fauna, the Puerco, is not known to occur in America except in the San Juan Basin of New Mexico. Outside of North America, fossils closely related to those of the Nacimiento group have been found in certain districts of Europe and South America, the European localities being confined to France and Belgium, where fossil mammals are known in the early Eocene corresponding closely to those of the Torrejon formation, while fossil mammals more nearly related to those of the Puerco formation are found in Patagonia.

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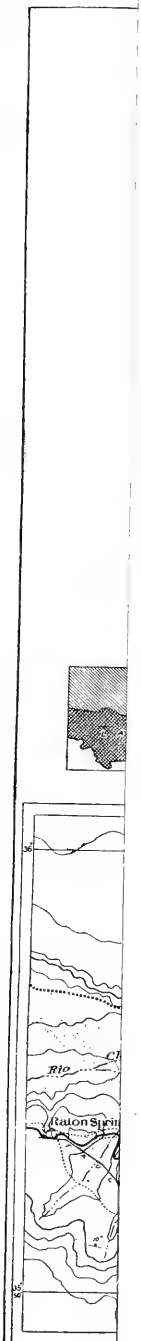
A NEW EROSION CYCLE IN THE GRAND CANYON DISTRICT, ARIZONA

H. H. ROBINSON

INTRODUCTION

The Grand Canyon District of Arizona possesses a particular interest for the geologist in that its history, at least from the beginning of the Tertiary, must be interpreted almost entirely from physiographic data; that is to say, the region has been subject to erosion for so long a period that stratigraphic evidence is lacking. The absence of such evidence, which long usage has fixed as the conventional means of interpreting geologic history, may have caused, perhaps, some doubt to be felt as to the reality of the conclusions originally reached by Dutton in 1882 in regard to the history of the region, for at that time the data of physiography were in a more or less embryonic state and their interpretative value was hardly recognized. Indeed, Dutton's report on the Tertiary history of the Grand Canyon District[1] was a pioneer work in this branch of geology and its significance becomes increasingly apparent with the passage of time. Today conditions are changed, physiography has taken its place as a systematic science, and the relation between topographic forms and the conditions under which they may originate may be considered as resting on a reasonably broad and well-established foundation. Thus conclusions based upon physiographic evidence are now accepted as of equivalent value to those based on older and more conventional lines of evidence, where twenty-five years ago they were looked upon with skepticism by the majority of geologists who had not had a physiographic training. That there was good reason for this attitude is well illustrated by the new erosion cycle described in this article, for the facts upon which it is based have been known for twenty-five years without their significance being fully

[1] *Tertiary History of the Grand Canyon District, Arizona, with Atlas* (Monogr. II, U.S.G.S., 1882).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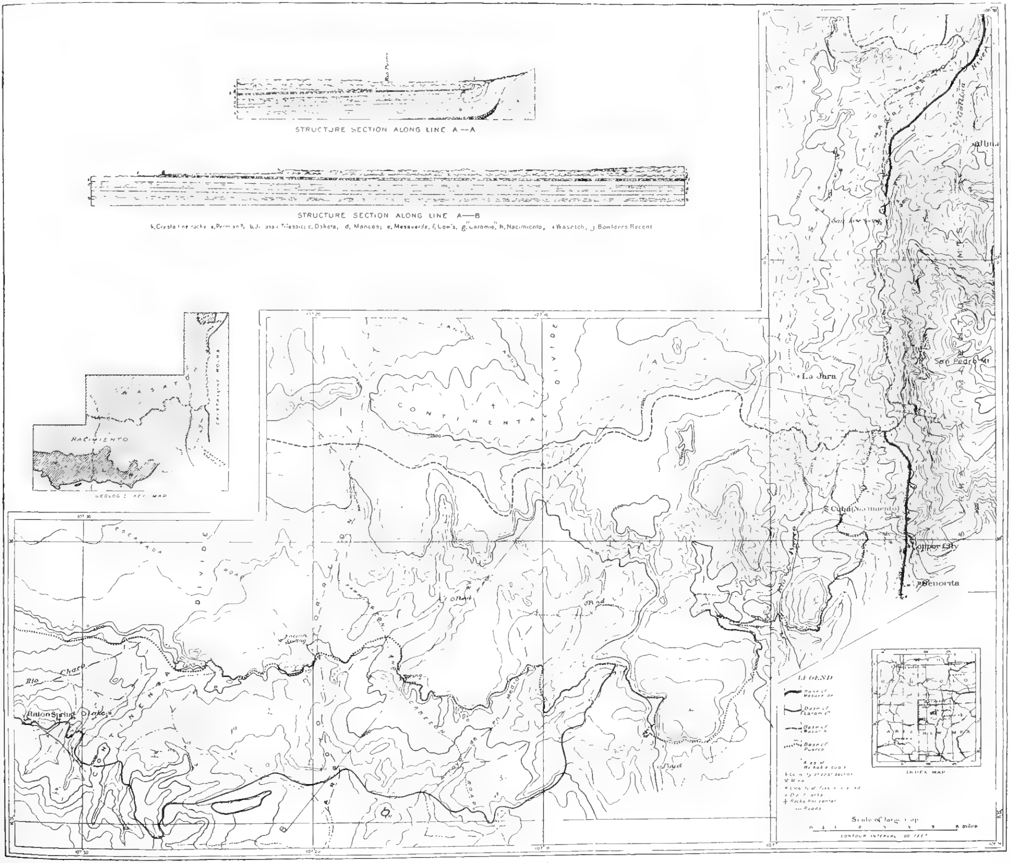

MAP OF THE PUERCO AND TORREJON TYPE LOCALITY
NEW MEXICO.

appreciated, thus indicating the recent nature of the growth of physiography from the descriptive to the broader interpretative stage.

REVIEW OF FORMER WORK

It will assist in understanding the bearing of this new cycle of erosion on the Tertiary history of the region if a partial summary of some of the former work is first presented. The actual amount is, indeed, not great, considering the length of time the region has been known and its interest recognized; possibly the extent of the field and the evident inaccessibility of much of it have exercised a deterrent influence.

The nature of the plateau problem was clearly appreciated by Newberry who in 1858 was the second geologist to traverse the region. His route lead him along the southern side of the Grand Canyon, and the conclusion he reached from the character of that and other parts of the plateau was that erosion had been the predominant factor in producing the relief. The following quotation will give his point of view:

> . . . . Before returning to the details of the local geology of our route, I ought perhaps to refer briefly to two questions of general importance, which would naturally suggest themselves to any geologist who should traverse the table-lands west of the Rocky Mountains, or should receive an accurate description of them from others.
>
> The first of these questions is: To what cause is due the peculiar topographic features of the surface of the table-lands—where different formations succeed each other in a series of steps, which generally present abrupt and wall-like edges—the more recent strata occupying the highest portion of the plateau?
>
> The first question belongs appropriately to the subject of surface geology, and will be referred to again. I may say here, however, that, like the great canyons of the Colorado, the broad valleys bounded by high and perpendicular walls *belong to a vast system of erosion, and are wholly due to the action of water.* Probably nowhere in the world has the action of this agent produced results so surprising, both as regards their magnitude and their peculiar character.[1]

The first extended account of the region, however, did not appear until 1882 when Dutton's *Tertiary History of the Grand Canyon District* was published. The history of the region as

[1] *Report on the Colorado River of the West. Explored in 1857–1858, by Lieut. J. C. Ives.* Washington, 1861. Part III, Geological Report by J. S. Newberry, p. 45.

deciphered by Dutton, and omitting many details of an admittedly speculative character, comprised the following events:

1. A period of great denudation during which a thickness of strata averaging 10,000 feet was removed from over an area of 13,000 to 15,000 square miles. This period ended somewhere about the close of the Miocene.

The Grand Canyon platform then may have lain near sea-level, and the remnants of Mesozoic beds . . . . were gradually obliterated, and the entire region was planed down to a comparatively smooth surface [p. 119] . . . . and was at a base-level of erosion [p. 120].

2. A canyon-cutting cycle. This was initiated by an epoch of faulting at the beginning of the Pliocene which elevated the region from 2,000 to 3,000 feet above the level it occupied at the close of the period of the great denudation.

At the epoch when the cutting of the present Grand Canyon began, no doubt the region at large presented a very different aspect from the modern one. While the greater part of the denudation of the Mesozoic had been accomplished, there were some important remnants left which have been nearly or quite demolished in still more recent times [p. 223]. . . . . The uplifting forces suspended operations for a time, and the drainage system sought a new base-level. During this paroxysm of upheaval the outer gorge of the Grand Canyon was cut, the river corrading down to the level of the esplanade in the Kanab and Uinkaret divisions, but below that horizon in the Kaibab [p. 226]. . . . . The process of erosion during this second period of base-level was occupied in the only possible work under the circumstances, viz., sapping the newly formed cliffs of the canyon. The cliffs, thus attacked, receded away from the river, gradually developing the broad avenue of the outer chasm [p. 121]. . . . . We now come to the final upheaval which brought the region to its present condition. . . . . A new paroxysm of upheaval set in . . . . amounting probably from 3,000 to 4,000 feet. The narrow, inner gorge of the Toroweap was swiftly cut and it is in this respect a type of the lower depths of the entire canyon. . . . . The epoch at which this latest upheaval took place is no doubt a very recent one in the geologic calendar. It began most probably near the close of the Pliocene [p. 228].

The history of the region, as worked out by Dutton, may be tabulated as follows:

I. The period of great denudation lasting until the close of the Miocene.
II. Uplift by folding (?) and faulting at close of Miocene.
III. The canyon cycle of erosion.
  a) Cutting of outer gorge of Grand Canyon during the Pliocene.
  b) Uplift by faulting at close of Pliocene.
  c) Cutting of inner gorge of the canyon during the Quaternary.

Davis,[1] as the result of two trips through the region, advanced several pertinent arguments supporting the broad conclusion of Dutton that the Grand Canyon District had experienced two cycles of erosion separated by a period of pronounced uplift. In the absence of local fossiliferous evidence he designated the earlier period of the great denudation as the plateau cycle and the later one, in which the canyon cutting occurred, as the canyon cycle. Especially suggestive was his argument in favor of two cycles based on the relatively great retreat of the cliffs from the canyon on its north side as compared with the slight retreat of the upper walls of the canyon from the river, the correctness of which was later confirmed by independent evidence (*a*, p. 118). He pointed out that the esplanade of the Kanab and Uinkaret sections of the canyon was best explained as a structural feature and from a variety of considerations concluded "that while many partial cycles of erosion may have preceded the long pause during which the broad denudation of the plateaus was completed, only a single uplift and a single downcutting are recorded in the canyon" (*a*, p. 185). This conclusion has since been confirmed by Dr. L. F. Noble as the result of detailed field work in the canyon in the vicinity of Bass's camp.[2]

Of critical significance was the recognition by Davis of an important period of faulting during the plateau cycle of erosion distinctly separated from the later faulting at the beginning of the canyon cycle. Definite evidence was obtained that relief of at least 1,000 feet, due to this faulting, was obliterated during the plateau cycle and that by the end of that cycle the region in general had been reduced to a peneplain.

In speaking of the reduction of the region to a peneplain at the close of the period of great denudation, Davis says:

> It therefore seems legitimate to say that the peneplain, so far as one was developed at the close of the first cycle, lay in the Permian formation at some unknown height above the present plateau surface in the Kanab district; and that the Carboniferous platform as now exposed in the Kanab Plateau is a

[1] *a*) "An Excursion to the Grand Canyon of the Colorado," *Bull. Mus. Comp. Zoology, Harvard College*, XXXVIII, May, 1901; *b*) "An Excursion to the Plateau Province of Utah and Arizona," *ibid.*, XLII, June, 1903.

[2] Unpublished manuscript.

stripped and somewhat dissected plain [*a*, p. 139]. . . . . Since the uplift by which the canyon cycle was introduced, sufficient time has elapsed for an extensive removal of the weaker Permian strata from the plateau surface. . . . . Even the resistant upper Aubrey strata, revealed by the stripping of their Permian cover, early in the canyon cycle, have suffered a significant amount of dissection, as seems to be the case over much of the Kanab Plateau; but the dissection here is not so mature as that by which the higher Kaibab is characterized [*a*, p. 137].

The general conclusions reached by Huntington and Goldthwait, as the result of a study of the Toquerville District, Utah,[1] coincided with those of Davis outlined above, but as the work was of considerable detail they were able to present the problem with somewhat greater fulness than had previously been done. In particular they were able to show "that at the end of the inter-fault cycle of erosion (the period of great denudation) the whole country was physiographically mature or even old. Certain regions of soft strata, chiefly near the Colorado River, had been reduced very nearly to base-level forming the Mohave peneplain."

Evidence has been presented by the writer[2] showing that the region about the San Francisco Mountains,[3] south of the Grand Canyon, was also reduced to a peneplain which involved not only soft Permian and Triassic strata but also the highly resistant upper Aubrey cherty limestone. It was concluded from a study of the literature that the peneplain most probably covered the entire southern portion of the present Colorado Plateaus and extended, in the Bradshaw Mountains, into the Basin Range country of Arizona. The remnants of the peneplain are sufficiently numerous to make it certain that practically the entire Grand Canyon District was reduced to base-level at the close of the period

[1] "The Hurricane Fault in the Toquerville District, Utah," *Bull. Mus. Comp. Zoology, Harvard College*, XLII, February, 1904.

[2] "The Tertiary Peneplain of the Plateau District, and Adjacent Country, in Arizona and New Mexico," *Am. Jour. Sci.*, XXIV (August, 1907), 109–29.

[3] The term "San Francisco Mountains" is here used to designate a group of six large and several hundred small volcanoes and their associated lavas, which covers an area of some 2,000 square miles on the plateau south of the Grand Canyon. The group takes its name from San Francisco Mountain, the largest mountain volcano of the region.

of great denudation. The peneplain was developed over much of the region on the soft Permian and Triassic strata and owes its preservation to a capping of basalt. The extent of the peneplain and the fact that it is developed across the basset edges of strata varying in hardness from a compact sandstone to a barely consolidated marl, as at Black Point in the Little Colorado Valley and elsewhere, force the conclusion that a long period of time is represented, that the base of control was an oceanic body of water, and that consequently the region stood approximately at sea-level.

The history of the region, following Huntington and Goldthwait, may now be tabulated as follows:

I. Period of folding and flexing.
II. Erosion period.
III. The first faulting.
IV. Inter-fault cycle of erosion. Region reduced to a peneplain at close.
V. The later faulting.
VI. The post-fault canyon cycle of erosion.

Stripping of weak strata down to the upper Aubrey cherty limestone. Cutting of deep canyons. Refreshing of cliff profiles.

As bearing on what is to follow it may be noted that Davis, and also Huntington and Goldthwait, considered that the peneplain developed on the Permian and Triassic formations marked the close of the period of great denudation and that the stripping of these strata and the consequent exposure of the upper Aubrey limestone—the present surface rock of the region—occurred after the uplift which introduced the canyon cycle. Dutton also recognized the existence of a peneplain on Permian strata beneath the basalt cap of Mount Trumbull and at other localities (p. 224), and he also considered that the present surface of the plateau was likewise developed at a base-level of erosion (p. 118). He did not give these two planes of erosion distinct interpretative values, but used them as common evidence that the region stood at a low elevation at the close of the period of the great denudation. The proper discrimination between these two planes of erosion, as will appear in the sequel, gives the clue to an essential feature in the history of the Grand Canyon District which has not thus far been fully recognized.

THE ADDITIONAL EROSION CYCLE

The erosion cycle to which the remainder of this article will be largely devoted followed after the development of the extensive peneplain at the close of the period of great denudation but before the uplift which introduced the canyon cycle of erosion, and is to be associated with the former cycle rather than the latter. It was characterized by the widespread removal of a notable thickness of Permian and Triassic strata and the development of a thoroughly mature topography on the underlying resistant upper Aubrey cherty limestone—the present surface rock of the region. It will be called the post-peneplain cycle of erosion. The preceding cycle, which closed with the reduction of the region to a peneplain, will be designated as the peneplain cycle, while the latest cycle, as formerly, will be called the canyon cycle of erosion.

A striking feature of the Grand Canyon District, which impresses even the casual observer, is the pronounced contrast between the broad expanse of the smooth or but gently undulating surface of the plateau and the deep and precipitous walled canyons carrying the present drainage, a contrast that is highly suggestive of different conditions of origin.

In the region south of the canyon, with which the writer is particularly acquainted, the surface of the plateau is etched by an extensive system of shallow valleys of thoroughly mature form. They were first described by Newberry, in 1858, in the following terms:

> Where we crossed this divide it had the character of an elevated plateau, of which the surface has been considerably modified by erosion, and now presents many broad and shallow excavated valleys [p. 58].

Davis, in speaking of these valleys on the Coconino Plateau, says:

> . . . . We were much impressed with the maturity of their graded sides and floors, in contrast to the youthful expression of the precocious canyon. . . . . Furthermore, the contrast between the rapid wasting of the cliff in the canyon walls and the slow change of the mature valleys on the plateau strongly suggests that the processes represent different cycles of erosion [*a*, p. 120, and Fig. 2].

These old valleys are also well developed farther south in the vicinity of the San Francisco Mountains. Figs. 1 and 2 illustrate

the one which is located just southeast of Flagstaff. The perfect maturity of form which characterizes the small branches even to their very heads is well shown in Fig. 1. The slightly meandering course and mature side slopes of the main valley are seen in Fig. 2. The alluvial filling is suggestive of a well-graded condition of the stream, especially when taken in connection with the gently sloping sides. It is, however, a significant fact that the alluvium, which was deposited after the valley had acquired its

FIG. 1

mature form, extends to the head of the valley so that its deposition was independent of the grade.[1]

The region south of the canyon is, indeed, a network of these mature valleys, and it is to be presumed that the corresponding districts elsewhere are also covered with them. They occur on the Marble Platform, but have not been specifically described

[1] The same phenomenon is strikingly illustrated by the heavy alluvial mantles of the large volcanoes of the region which, on San Francisco Mountain, appear to be associated with glacial deposits. These alluvial deposits are now undergoing dissection, thus indicating a reversal of the conditions under which they were laid down.

as present on the Kanab Plateau. Apparently they are best preserved in those localities where they were developed on the upper Aubrey cherty limestone.

The valleys of the Kaibab (and also the Coconino) Plateau have been described by Davis as follows:

> The limestone [upper Aubrey] capping these plateaus is maturely dissected. Broad-floored, well-graded valleys with gently sloping sides ramify through the uplands in a most perfect manner, presenting a maturely developed form even to their heads; and this in spite of the fact that they are nearly always dry, for the wash of waste down their sides and along their floors is accomplished only during the rains and thaws of winter and occasional showers of summer [*a*, p. 120].

The above description embraces the valleys of the Coconino Plateau and also applies without alteration to the similar valleys farther south in the vicinity of the San Francisco Mountains. There is, therefore, little doubt, as will appear from later considerations, that all these valleys were developed in the same cycle of erosion. It may be noted, moreover, that, as these valleys had maturely developed form even to their heads, their lower courses must have originally possessed at least equal maturity of form, so that there is no doubt as to the thoroughly mature development of the topography throughout the Grand Canyon District during this cycle.

The post-peneplain cycle of erosion is separated from the preceding cycle of the great denudation, which closed with the widespread development of a peneplain, not only because of differences in topographic expression, but primarily because the mature topography occurs at a level distinctly below that at which the peneplain is found. This is a fact that is perfectly evident at many localities where structural complexities are absent. As, however, the peneplain involves a considerable thickness of strata ranging from the upper Aubrey (upper Carboniferous) limestone through Triassic formations, while the mature topography, so far as known, is developed, or at least preserved, only on the upper Aubrey limestone, the actual difference between the two planes of erosion is a variable one depending upon the thickness of Permian and Triassic strata that may be present at any locality.

In the vicinity of Flagstaff, close to the boundary between the upper Aubrey limestone and Moencopie (Permian) formation, the difference between the two planes of erosion is not over 200 feet. Along the eastern side of the Black Mesa, farther south, it ranges from 400 to 600 feet. At Cedar Ranch, 15 miles northerly from San Francisco Mountain, it has increased to 700 feet, while at Red Butte, nearer the canyon, it reaches a maximum of about 1,000 feet. Corresponding differences between the two planes of erosion

FIG. 2

occur on the north side of the canyon. In the southwest section of the plateau the difference is practically nothing, since the peneplain was developed on the upper Aubrey limestone and the forces of erosion, which were powerful enough to remove the in general weak Permian and Triassic strata elsewhere, had little effect on the resistant basalt capping the peneplain and on the underlying limestone. The only locality in the district which appears to have surely risen above the peneplain at the close of the period of the great denudation is the Kaibab Plateau. The surface

of this plateau is a stripped structural one formed by the upper Aubrey cherty limestone, and its elevation above the surrounding plateau country is due principally to monoclinal folding which occurred not later than the very beginning of the erosional history of the region in the Eocene. It must be supposed, then, that the surface of the Kaibab Plateau was reduced to maturity or old age, coincident with the development of the peneplain, and that its present mature topography represents a continuation of the process in the post-peneplain cycle of erosion.

The separation of the post-peneplain cycle from the canyon cycle which followed is based in part on the wide difference in the character of their drainage systems, the one perfect in its maturity, the other equally perfect in its youthfulness, and the fact that the canyon cutting has to some extent destroyed the mature valleys. There is abundant evidence that this latter process is still in progress; it is very plainly seen on both the north and south sides of the Kaibab section of the Grand Canyon where the older mature valleys are being consumed by the widening of the youthful canyon. Further, the courses of many of the partly consumed valleys lead away from the canyon, thus indicating that there has been such a radical readjustment of drainage lines in the canyon cycle as to bring about definite changes in their direction, and this is especially noticeable in the case of the trunk stream of the region—the Colorado River.

The tracing out of the mature valleys and reconstruction of the drainage system of the post-peneplain cycle of erosion is evidently an important problem which must be worked out before a satisfactory explanation for the location of the present canyon system of drainage can be offered. For the reconstruction of this mature drainage system should permit a definite idea of the attitude of the land during the post-peneplain cycle to be formed and consequently indicate the extent and magnitude of the regional warping which followed. Of equal importance, also, would be a study which would permit the reconstruction over an extensive area of the peneplain of the preceding cycle of erosion; this would assist in determining not only the extent of the warping but also the magnitude of the faulting which has occurred at various times in

the history of the region. Indeed, if the supposition is as correct as it appears to be that the ancestors of the Colorado River, several generations removed, had their courses originally determined by the configuration of the peneplain, it is evident that the peneplain must have embraced practically the entire area of the Colorado plateaus, and consequently this problem presents a very wide interest.

A comparison of the extent of erosion, taken in connection with the conditions under which it was accomplished, during the post-peneplain and canyon cycles furnishes added reason for separating them. The figures which follow are, of course, the roughest approximations, but they may serve to give some idea of the amount of material eroded. And first it may be noted that the period of the great denudation is distinctly in a class by itself. Taking Dutton's estimate of an average thickness of 10,000 feet of strata removed over an area of 13,000 square miles, the volume eroded is equal to 25,000 cubic miles; or a more conservative estimate, with the thickness of strata placed at 6,000 feet, is 16,000 cubic miles. The amounts of material eroded during the post-peneplain and canyon cycles were very much smaller; it is estimated that their combined volume is only about 5 to 10 per cent of that removed in the period of the great denudation.

The amount of material eroded during the post-peneplain cycle is placed at 800 cubic miles. This is based on the removal of an average thickness of 500 feet of Permian and Triassic strata from an area of some 8,000 square miles. The latter figure shows how widespread was the stripping of the soft strata overlying the resistant upper Aubrey limestone during this cycle. In view of so extensive a denudation ending, as it did, with the development of a mature topography of only slight relief, the conclusion seems justified that the region during this time must have stood at no great elevation above the sea.

The amount of material eroded during the canyon cycle is considered as equal to the volume of the various canyons of the region, which practically means the Grand Canyon and its tributaries, and in addition some volume of soft strata removed by stripping. This latter process has been confined to limited areas and the volume of material thus removed cannot well be calculated;

it is, therefore, arbitrarily placed at 50 cubic miles, which allows for the removal of over 100 feet of strata from an area of more than 2,000 square miles. Including this, the total volume of material eroded during the canyon cycle is placed at 600 cubic miles.

A contrast may thus be drawn between the removal of 800 cubic miles of Permian and Triassic strata over an area of some 8,000 square miles with the development of a mature topography on the stripped resistant limestone—the post-peneplain erosion—while the land stood at a fairly low elevation, and the erosion of 600 cubic miles of material as the result of canyon cutting—the canyon erosion—with the land at, or rising to, a high elevation. If it is asked whether the erosion above described occurred in a single cycle, the answer must be in the negative. For erosion in the canyon cycle has been proceeding at an extremely rapid rate and consequently the 600 cubic miles of material removed in the cutting of the youthful canyons indicates much too short a time to permit the stripping of the 800 cubic miles of Permian and Triassic strata from the surface of the plateau and the development of the mature topography on the underlying limestone. To consider the post-peneplain erosion as occurring in the same cycle as the canyon erosion is to include the greater within the lesser, thus producing an anomalous result. If, on the contrary, a thousand cubic miles of material had been eroded in the canyon cutting and but a few hundred stripped from the surface of the plateau, and especially if the mature topography had been developed on weak instead of resistant strata, it might be supposed to have entirely occurred in a single cycle. But in view of the evidence furnished by the mature valleys, the differences in direction between the mature and canyon systems of drainage, the relative amounts of erosion in the post-peneplain and canyon cycles, and the differences in the resistance of the strata eroded in the two periods, the conclusion is fully justified that the erosion of the post-peneplain and canyon cycles could not well have taken place in a single cycle and consequently the post-peneplain cycle must be given an independent rank.

An important consideration in separating the post-peneplain cycle of erosion from the preceding peneplain cycle and especially from the succeeding canyon cycle lies in the fact that the mature

topography of the intermediate cycle was developed on what was evidently, under the circumstances, a highly resistant formation, namely, the upper Aubrey cherty limestone. This formation is as resistant, for instance, as the basalt which was erupted after the development of the peneplain at the close of the period of the great denudation and is very much more resistant than the overlying Permian and Triassic strata remaining after the development of the peneplain. A comparison of the amount of erosion during the post-peneplain cycle in the extreme southwestern part of the plateau, where the limestone and basalt were present, and the remainder of the district which was covered, for the most part, with Permian and Triassic strata, is very instructive upon this point. The basalt in the former locality was only moderately dissected, and the limestone only slightly, as the result of erosion during the whole of the post-peneplain cycle, while elsewhere Permian and Triassic strata up to a maximum thickness of over 1,000 feet were removed. The difference suggests how erroneous might be an idea of the erosion based on incomplete observations. The point to be noted is that the development of a thoroughly mature topography, even of a low degree of relief and representing no great removal of material, on so resistant a formation as this limestone is indicative of an erosion interval as long in itself, perhaps, as that marked by the canyon cutting. And when to the time required for the development of the mature topography on the resistant limestone is added that necessary for the previous extensive and widespread removal of the overlying Permian and Triassic strata an interval is indicated which was probably much longer than that covered by the cutting of the youthful canyons. Moreover the strata involved in the latter process are not all so resistant as the upper Aubrey limestone on which the mature topography was developed. Several important formations are distinctly weaker, as, for example, much of the lower Aubrey red sandstone, and the presence of these weaker beds tends to increase the difference between the lengths of time required for the canyon cutting and post-peneplain erosion in favor of the latter. The interval covered by the post-peneplain cycle of erosion was very much shorter, of course, than that of the preceding period of the great denudation,

but, on the other hand, it certainly appears to have been much longer, taking the various factors into account, than the time required for the canyon cutting.

The evidence, therefore, indicates that the post-peneplain cycle of erosion should be clearly marked off from the preceding peneplain cycle and from the succeeding canyon cycle. The history of the region, as previously given, must be amended, consequently, by saying that after the close of the peneplain cycle of erosion, and the widespread eruption of basalt, another period of erosion began during which unprotected Permian and Triassic strata up to a thickness of 1,000 feet were removed from an area embracing the greater part of the Grand Canyon District. Where these strata were protected by the basalt their removal was incomplete and remnants now form the mesas and buttes, such as Mount Trumbull and Red Butte, which are found at various localities. It is also to be inferred from the widespread removal of these strata that the high cliffs bounding the region on the north and east experienced a further retreat. Davis says: ". . . . in the case of the Vermillion cliffs at Pipe Spring the retreat is likely, it seems to me, to have been several miles at least" (*b*, p. 37). After the removal of the Permian and Triassic strata erosion proceeded still farther and developed a mature topography of low relief in the underlying and resistant upper Aubrey cherty limestone and to a less extent in other formations. The revival of the forces of erosion is supposed to have been brought about by a slight elevation of the region above its stand at the close of the peneplain cycle. It is considered that the uplift was associated with a period of faulting, which has thus far not been specifically recognized. The movements of different periods have so often taken place along the same line of displacement in this region that detailed study is necessary in order to discriminate between them.[1]

[1] In a paper entitled "A Geological Excursion in the Grand Canyon District" (*Proc. Boston Soc. Nat. Hist.*, May, 1909) and published since the above was written, Dr. D. W. Johnson describes a third period of faulting on the Hurricane displacement in the vicinity of Toquerville, Utah. It occurred between the faulting of the plateau cycle—the first faulting of Huntington and Goldthwait—and that which introduced the canyon cycle of erosion, and amounted to about 1,000 feet. This appears to be the faulting which is here supposed to have immediately preceded the post-peneplain cycle of erosion.

The history of the Grand Canyon District, with the post-peneplain cycle of erosion introduced, may now be summarized as follows:

I. Period of folding and flexing.

II. Erosion cycle.

III. The first period of faulting. A period of extensive faulting.

IV. The peneplain cycle of erosion. This cycle closed with the widespread development of a peneplain. Relief produced by faulting (III) entirely obliterated. Widespread volcanic activity, marked by the eruption basalt, occurred shortly after the development of the peneplain and while the region still stood close to sea-level.

V. The second period of faulting. Faulting probably of less magnitude than that of the first and third periods.

VI. The post-peneplain cycle of erosion. Widespread stripping of Permian and Triassic strata and development of a mature topography on the underlying beds, principally the upper Aubrey limestone, at a horizon ranging from zero to 1,000 feet below the level of the peneplain. Further retreat of the high cliffs on the north and east sides of the district. Land stood at no great height above the sea.

VII. The third period of faulting, with broad regional uplift. Region raised from 4,000 to 6,000 feet above the position it occupied at the close of the post-peneplain cycle.

VIII. The canyon (present) cycle of erosion. Marked by the development of a canyon system of drainage of extreme youthfulness. Refreshing of cliff profiles. Erosion otherwise very slight.

The history above outlined is considerably more complex than that presented by Dutton and is believed to be complete so far as the principal events are concerned. It differs from previous interpretations in introducing the post-peneplain cycle of erosion, and it is felt that this cycle rests on evidence fully as conclusive as that which establishes the separate existence of the peneplain and canyon cycles of erosion. It removes the anomaly in the previous explanations of the widespread stripping of a very considerable thickness of Permian and Triassic strata and development of a mature topography on the resistant upper Aubrey limestone in the same cycle that has witnessed the cutting of the youthful canyons.

POSITION OF EVENTS IN GEOLOGIC TIME

While the history of the Grand Canyon region, on the whole, possesses a very reasonable definiteness, the problem of placing the several events which comprise it in geologic time is quite unsatis-

factory, as there is no direct evidence to be derived from the district itself. The only method of attack is by correlation with the neighboring Basin Range country of Nevada, which in itself has not been studied in any great detail. Yet, notwithstanding the tentative nature of any conclusions that may be reached, it is desired to present the results of such a correlation, not only because they differ from those previously reached, but also because it is believed, in the light of known geologic events of recent date—especially in California—that they possess a very considerable suggestive value and may be useful to those who may later have occasion to study this general region.

The folding and flexing (I), as represented by the Kaibab and Echo Cliff monoclines, does not antedate the middle part of the Eocene, since the disturbance involves strata of Lower Eocene age in the high plateaus of Utah.[1] It seems probable, also, from other considerations, that it did not occur later than the end of the Eocene. The folding in the Grand Canyon District, to all appearances, is of the same age; it must be carefully distinguished, however, from certain broad warpings of much later date. Up to the present the folding and flexing movements have received much less study than the later faulting, although they are fully equal to the latter in importance, when their magnitude and extent, and the geographic changes involved are considered.

The correlation of greatest probability is that between the peneplain developed at the close of the peneplain cycle of erosion (IV), and the mature topography and local peneplains of the Basin Range country of southern Nevada and of Arizona. The point has not been so thoroughly studied as is desirable, but it seems clear to the writer, as the result of reconnaissance work, that there was originally a direct continuity between the maturely dissected Basin Ranges with local peneplains extending from their footslopes and the more distant highly developed peneplain of the present plateau region; they were the related parts of a single physiographic province. There is little doubt that this transition may be actually traced in Arizona, with only minor breaks, from the Bradshaw Mountains through the Black Hills on the west side of the

[1] Dutton, *op. cit.*, 74.

Verde Valley into the Black Mesa on its east side. At many points in the Black Hills and the mountains the remnants of the plain are capped by a basalt identical in character with that which covers the peneplain on the Black Mesa. Also the amount of erosion that has occurred since the basalt was erupted on the plain east of the Bradshaw Mountains compares very favorably with that of the post-peneplain cycle in the near-by present plateau region.[1] As both areas were situated in local drainage basins under similar climatic control and as the strata involved, judging from more recent results in the Grand Canyon of the Colorado, possessed approximately equal erodability, it may be concluded that the topography of the two areas was of contemporaneous origin.

The date at which the Basin Ranges originated as tilted block mountains possesses, therefore, a critical value, since it marks the time between which and the present the most clearly known events in the history of the Grand Canyon District occurred. This date is fixed by the age of certain formations—Pah-Ute of King and Siebert of Spurr—which were involved in the range-making movement. A Miocene age was originally assigned to these beds by King[2] and this has since been concurred in by Spurr,[3] Ball,[4] and Ransome.[5] The determination is not so positive as might be desired, nor is it certain that the entire Miocene is represented. In the absence of evidence to the contrary, however, it will be assumed that the sedimentary beds involved in the range-making do represent the whole of the Miocene. The probable correctness of this assumption is indicated by following consideration. If the strata involved in the mountain-making represented only the earlier part of the Miocene and the faulting which gave rise to the ranges as tilted block mountains occurred, for instance, in the middle of the Miocene, then the succeeding formation should be of late Miocene age, since the region during this time was a land area and the deposits were of a local nature. On the contrary, however, the next youngest formation is of Pliocene age; it rests unconformably on the older tilted strata of the ranges generally in a horizontal or

[1] H. H. Robinson, *op. cit.*, 120.

[2] *Explor. 40th Parallel*, I, 412–24.

[3] *U.S.G.S.*, XLII (1905), 66.

[4] *U.S.G.S.*, Bull. 308 (1907), 32.

[5] *U.S.G.S.*, LXVI (1909), 66.

but slightly disturbed position. On this basis, then, the Basin Ranges originated as tilted block mountains at the close of the Miocene.

It is to be noted that the relief produced by the extensive faulting, which followed in the present plateau region next after the Eocene folding, was entirely reduced in the development of the peneplain. A very considerable interval, therefore, must have intervened between the time of the faulting and the final degradation of the region to a peneplain. In view of the magnitude of the faulting and its time relation to the peneplain, it seems permissible to correlate it with that which gave rise to the Basin Ranges as tilted block mountains, and which likewise followed a period of folding.

After the faulting at the close of the Miocene the newly formed block mountains of the Basin Range region were attacked by erosive forces and reduced to mature forms. Contemporaneously local peneplains were developed, under favorable conditions, about the footslopes of the ranges,[1] while at greater distances—in the present plateau region—a highly developed peneplain covered thousands of square miles. There is at present no direct evidence to tell when this erosion cycle came to an end, so that it is necessary to make an assumption as to this date. It is the writer's opinion, based on the character and extent of the erosion in the several cycles through which the Grand Canyon region has passed, that the close of the peneplain cycle should be placed at the end of the Pliocene. This appears to be the most probable date when the volume of the erosion during the peneplain cycle and the widespread base-leveling are compared with the extent and nature of the erosion during the post-peneplain and canyon cycles. The point is one that is difficult to settle and may always remain, perhaps, a matter of individual judgment.

As the result of the foregoing assignment of dates, the post-peneplain and canyon cycles of erosion, with the pronounced faulting that came between them, are placed in the Quaternary. This is at variance with previous ideas. Dutton, for instance, spread the canyon cutting alone over both the Pliocene and Quaternary;[2] a previous correlation by the writer confined it to the

[1] Ball, *op. cit.*, 41. [2] *Ibid.*, chap. xii.

Quaternary,[1] while the present one throws it still farther forward into the latter part of that period. Granting the correctness of the assumptions previously made, the reasonableness of this conclusion seems evident when the relative amounts of erosion during the post-peneplain and canyon cycles, and the wide difference in the conditions under which it was accomplished are considered, although the correctness of the results in general remains for future demonstration. It is suggestive of the truth of the conclusion here reached, however, that Lee in his bulletin entitled "A Geological Reconnaissance of Western Arizona"[2] describes, at a number of localities, a thick unconsolidated gravelly formation that has experienced marked faulting. In speaking of this formation as it occurs in the Chemehuevis Valley, he says:

> The older gravels are horizontally bedded in some places but in others are faulted and highly inclined. . . . . In general appearance they resemble the Temple Bar Conglomerate and are provisionally correlated with it.[3]

The suggestive point is that the Temple Bar Conglomerate is considered as being of Quaternary age and deposited after a last period of pronounced faulting at the opening of the Quaternary, so that it should be comparatively undisturbed. If one may judge, however, from Lee's descriptions and cross-sections, the formation which he provisionally correlates with the Temple Bar Conglomerate has been very strongly faulted and tilted at a number of localities. This is easily explained, and Lee's correlation strengthened, if the major faulting which introduced the canyon cycle of erosion occurred during instead of at the beginning of the Quaternary. For with the faulting occurring during the middle or latter part of the Quaternary there would still have been ample time in the earlier part of that period for the deposition of heavy alluvial deposits upon the lowlands bordering the plateau country.

There are three other points which may receive further mention. One is that on the basis of the erosion cycles in the Grand Canyon district the mature topography of the Basin Ranges of southern Nevada and of Arizona should be considered as the result not only of the peneplain but also of the post-peneplain cycle of erosion. The former was much the more important, but the latter may have introduced significant modifications. Whether they would be

[1] *Ibid.*, 111. [2] *U.S.G.S.*, Bull. 352 (1908). [3] *Ibid.*, 43–44.

recognizable in the ranges themselves is questionable. Judging from the changes produced by erosion during the post-peneplain cycle in the plateau region, they should be most easily recognized about the footslopes of the ranges and in the peneplained areas.

A second point is that while the Basin Range country and plateau region, as they are known today, were probably to some extent differentiated at the close of the Miocene, the line of demarkation between the two regions was more or less obliterated, at some localities entirely, by the close of the peneplain cycle of erosion, which has been placed at the close of the Pliocene. At that time the Basin Range country in general constituted the uplands whose lowlands were situated, in part at least, in the present Grand Canyon District. At the close of the Pliocene the faulting appears to have been of such a nature that the two districts were again to some extent separated, but it was not until the pronounced faulting which introduced the canyon cycle of erosion that the Basin Range and Plateau provinces, as they are known today, were given, or began to be given, what has since developed into their maximum degree of demarkation.

It may also be noted, as a climatic incident in the history of the region, that a small glacier lived in the large interior valley of San Francisco Mountain, situated on the plateau south of the Grand Canyon, during the canyon cycle of erosion. An attempt has been made to calculate the temperature on the mountain at the time of the glaciation; the problem was approached by three different methods and the results showed reasonable agreements. Without going into the processes of calculation, which are reserved for a future paper, it may be said that the average result gave a temperature of 15° F. less than that of today. This result is in close agreement with determinations made elsewhere, and as it is a fair assumption that the region has experienced only slight changes in elevation since the glacier existed on the mountain, it may be taken as an approximate measure of the difference in temperature in this general region between what was certainly one of the latest and perhaps the last stage of the Glacial period and the present time. It is evident that if conditions were only sufficiently favorable for the existence of a small glacier on the mountain after the region had been elevated possibly as much as 5,000 feet at or

since the beginning of the canyon cycle of erosion they must have been very unfavorable for the existence of any glaciers during the post-peneplain cycle when the region stood nearer sea-level, unless the estimates of temperature during glacial time are much in error. It may be concluded, then, that San Francisco Mountain has experienced only the one period of glaciation which occurred in late Quaternary time.

The Tertiary history of the Grand Canyon District, with geologic dates assigned as given in the preceding pages, may be summarized in conclusion as follows:

I. Period of folding and flexing during the latter half or at the close of the Eocene.

II. Erosion period during the Miocene.

III. First period of faulting at close of the Miocene. A period of extensive faulting. It is correlated with the faulting that gave rise to the Basin Ranges of southern Nevada as tilted block mountains.

IV. The peneplain cycle of erosion during the Pliocene. The Miocene and Pliocene erosion, which are considered as constituting the latter and greater part of the Period of the Great Denudation, closed with the widespread development of a peneplain. This is correlated with the mature topography and local peneplains of the Basin Range country of southern Nevada and of Arizona. Relief produced by previous faulting (III) largely and at some localities entirely obliterated. Widespread volcanic activity, marked by the eruption of basalt, occurred shortly after the development of the peneplain and most probably while the region still stood close to sea-level.

V. The second period of faulting at the close of the Pliocene. Movements probably of less magnitude than those of the first and third periods.

VI. The post-peneplain cycle of erosion during the first part of the Quaternary. Widespread stripping of Permian and Triassic strata and development of a mature topography of low relief, principally on the upper Aubrey limestone, at a horizon ranging from zero to 1,000 feet below the level of the peneplain. Further retreat of the high cliffs on the north and east sides of the district. Land stood at no great height above the sea.

VII. The third period of faulting, with broad regional uplift, during the middle or latter part of the Quaternary. Region raised from 4,000 to 6,000 feet above the position it occupied at the close of the post-peneplain cycle of erosion.

VIII. The canyon cycle of erosion during the latter part of the Quaternary. Marked by the development of a canyon system of drainage of extreme youthfulness. Refreshing of cliff profiles. Erosion otherwise very slight. Colder atmospheric conditions prevailed during part of this cycle, at least, as indicated by the existence of a small glacier on San Francisco Mountain.

EDITORIAL

Are there line fences in science?

In the early days when the untilled prairies of the great American midland were broad and the tillers few, it was the rule to leave wide "turnrows" of virgin sod next the line fences. At a later stage these came to be almost the only virgin ground left, and they lingered here and there as the choicest residues of primitive fertility and native life. Since these in turn passed away, the tillage of each field has pressed hard on its neighbor's ground. It has been somewhat so in the scientific domain. The once neglected turnrows have become the fields that most invite culture. But this has been said before.

Notwithstanding this parallel, one is sometimes prompted to ask if there are indeed line fences in science. Have metes and bounds of ownership been set, at which one's work must stop? May the arbitrator say: To this point you may plow and plant, but no farther? Or is the tillage of the sciences reciprocal like the cropping of the cereals and the legumes? The more they are interplanted, within limits, the better for *both* crops, the Chinese say.

The question is concrete and takes sharp outline only through a concrete case. In citing such a case, matter may thereby get into print that is not in print, nor on the road to print; matter adjudged out of bounds, because it trespassed on others' fields.

It is permissible to cite such a case the more freely because the one in mind came at a time when bounds were shifting, when the chief parties in interest were absent or preoccupied. The case thus takes cover under the latitudinal functions of the important subordinate and the anonymous critic. It is moreover a case of friends among friends; it is not a scrap between hostiles. The case may not be material in itself, though it relates to an important inquiry, and lies at the threshold of an important enterprise. It

would become important—important as a signal—if it were talismanic or were to become talismanic.

The evolution of the Bureau of Mines from a branch of the national Geological Survey is a historical event of a high order of importance in the progress of science as an aid to human welfare. It is worthy of note that the evolution is coincident with a critical stage in the progress of the chief inquiry to which the bureau has set itself, the protection of life against preventable disaster. The imperative nature of this inquiry has been impressed upon the world by the appalling disasters of 1907. That the main source of such disasters lies in the explosibility of coal dust rather than in explosions of pre-existent gases, and in the improper handling of explosives as the exciting agency, had already been recognized by critical investigators and had been set forth measurably in the literature of the subject, but it had not been accepted widely enough to be effective with those in whose hands the remedy rests. The further work to be done to attain practical success lay in more convincing evidence of the sources of disaster, in the discovery of effective preventives and in such education respecting these as is requisite to their effective adoption, a task at once of research, of invention, of demonstration, and of inculcation, in which each factor is imperative to the success of the whole.

When the shock of the disasters of the fall of 1907 awakened intense interest in the problem, the initial steps toward finding a method of forestalling such calamities had already been taken in America, following earlier steps of like nature in England, France, Belgium, and Germany; but as yet these had not reached sufficiently impressive demonstrations of the sources of disaster and were occupied with doubtful devices for prevention. The line of preventive measures which now seems the most promising had, indeed, been suggested many years earlier, but on limited grounds. It had failed to be adequately stimulative; indeed it seems to have fallen into practical oblivion. The American movement thus entered an open and urgent field with little more than the handicap of lesser experience and of a younger and busier community.

With a wise sense of the value of co-operative methods, the

leader of the chief American movement chose for the investigation of the signal disasters in Pennsylvania and West Virginia an expert in explosives, an experienced inspector of mines, and a specialist in rock-gases. These worked co-operatively and yet in measurable independence. Less than two months after the inspection of the chief disasters, the specialist in rock-gases reported progress (February 15, 1908) of which the following is an extract:

SOME SPECIALLY SUGGESTIVE RESULTS

Another line of attack upon the problem which now looks as though it might lead to results of much importance was opened up last Tuesday when I made comparative analyses of the fresh coal, the uncharred dust, and the charred dust from a single room in No. 8 Mine at Monongah. In room No. 3 on the 3d right off the 2d north in Mine No. 8 we found the props heavily plastered with charred dust on the inby sides, while adhering to the outby sides of the same props was a thick deposit of uncharred dust. These dusts were in such quantities that cans were filled with samples of each which were collected with much care. At the same time a third can was filled with fresh coal taken from the rib a few feet away. This was ideal material for a comparative study. My analyses show the following results:

FRESH COAL

Moisture	1.24
Volatile matter	35.28
Fixed carbon	59.88
Ash	3.60
	100.00

UNCHARRED DUST

	First sample	*Second sample*
Moisture	2.30	2.34
Volatile matter	24.13	23.43
Fixed carbon	45.01	45.19
Ash	28.56	29.04
	100.00	100.00

CHARRED DUST

	First sample	*Second sample*
Moisture	1.13	1.20
Volatile matter	24.78	24.36
Fixed carbon	58.11	59.33
Ash	15.98	15.11
	100.00	100.00

An inspection of these analyses shows a striking difference in the percentage of ash. While a slight increase in the percentage of ash necessarily results

from the loss of the volatile matter this accounts for but a small part of the great increase in the ash from these two dusts over that in the original coal. The difference is clearly due to the admixture of finely powdered shale swept up by the explosion. Small fragments of shale were readily recognized in the ash residue after the carbon had all been burned out. A fact which I believe to be of great significance is that *the uncharred dust contains nearly twice as much ash (shale dust) as the charred dusi.* These dusts came from the opposite sides of the same identical props in a room into which the flames penetrated. Both dusts must have been subject to the explosion and yet they are very different in composition, the difference everywhere in the room depending upon which side of the prop the dust was located, the explosion having served as an admirable sorter. Now the explosion did not originate in this room, but advanced into it from the entry, and the outby sides of the props against which the dust was forcibly driven by the explosion are coated with dust containing nearly twice as much shale dust as is contained in the charred dust on the inby exposures of the props. The other and most significant difference is that the dust (on outby exposures) containing *28 per cent of ash and shale* is *not charred* while the dust (on inby exposures) which contains *only 15 per cent of ash and shale* is *charred* and has lost much more of its volatile hydrocarbons.

The differences in the charring of the dust and in the proportion of fine shale in the dust, I believe, are interrelated, one being the result of the other. The explanation, I think, is this: The dust is driven against the outby sides of a prop with much force but not with equal force, the shale particles by reason of their density being driven against it with greater force and hence more likely to stick. The portion which adheres on the outby side of the prop therefore contains more shale dust and less coal dust than an average sample. In the lee of the prop there is a reduced pressure, and an eddying current laps around against the inby side and permits more quiet adhesion. Now the specific gravity of this coal is 1.30 while that of average shale is about 2.60, which is just twice that of the coal. The coal dust is also likely to be finer than the particles of shale. Hence much of the heavier shale particles will be carried on past the post, while the weaker eddying current which touches the lee side will contain a much higher percentage of the lighter coal and less of the heavier shale. This explains the difference in the percentage of ash brought out so strikingly by the analyses.

The high percentage of shale in the dust by diluting the combustible dust and absorbing much of the heat necessary to inflame it has had such a dampening effect upon the combustion that the coal dust which was driven against the props directly was not charred. But in the lee of the props where the proportion of non-inflammable shale has been much reduced and the expulsion of the volatile combustibles is favored by the partial relief of pressure and the slower current, the dust yields up to the flame much more of its inflammable gases and becomes charred or even coked.

. . . .

In addition to the theoretical and scientific interest attached to this new idea, I think this line promises much of practical value in the prevention of dust explosions, and these are the most disastrous of the mine explosions. If the presence of a certain proportion of shale dust mixed with the coal dust greatly reduces the explosibility of the latter, and reduces the volume of combustible gases which are fed to the flame so that the dust is not charred, it would seem that the addition of somewhat more pulverized shale would render the dust incapable of propagating an explosion. The force of the explosion itself gathered up 25 per cent of shale dust and if more shale were added artificially to the dust in the entries and rooms an explosion, even if once started, which would be much less likely, might snuff itself out before traveling throughout the whole mine. The addition of shale to the coal dust should be a comparatively simple matter. As soon as wet, by forming mud it should adhere to the coal dust and prevent the latter from becoming stirred up into the air for a long time after it had dried. Perhaps a very effective way to treat the dust would be to use a sort of shale douche made by mixing into the water used in sprinkling a mine a certain quantity of finely ground shale. While sprinkling with water alone does little good after the water has dried up, which takes place rapidly in winter, a shale douche by covering the coal dust with a thin coating of fine shale should keep the dust in a condition unfavorable for an explosion for some time after the water had dried. This being so, stronger ventilation could be used to remove the gas without the increased danger of a dust explosion.

A fuller report embracing further work was submitted later in the year. In the absence of the chief from the Washington office, this had an experience not altogether unknown in official practice. In the wisdom of the vicarious authority then regnant it passed beneath the blue pencils of unknown critics who found, among other things, that its furrows ran over the bounding line of the geo-chemical field and turned up some things thought to lie in the domain of engineers. It is not known that the critics were engineers and so naturally subject to sensitiveness as to the metes and bounds of the engineering field. The internal evidence implies that they were not engineers, at least not engineers acute to see what was latent in the geo-chemist's suggestions. At any rate the suggestions of the rock-gas expert were heroically blue-penciled. Their author, while arguing their legitimacy and their stimulative, directive, and educational value, made no appeal to the men higher up. It is not comfortable or diplomatic to make such an appeal when the merits or the good taste of one's products are in

question, and so, as a compromise, or as a mitigation of the surrender, if you please, the emasculated section that laps from p. 55 over onto p. 56 of *Bulletin 383*, U.S. Geol. Survey, on "Explosive Mine Gases and Dusts with Special Reference to Explosions in the Monongah, Darr and Naomi Coal Mines," is all that found its way to the printer. Whether the intervention of unknown critics between governmental investigators and the public is wholesome or unwholesome no doubt depends on the competency of the criticisms, the spirit in which they are made, and the degree of insistence of the officer in charge as to how far the author must accept or must bow to them. In cases permissible to cite—and this seems to be one—the scientific public may be glad to know in concrete detail how the system works in actual practice where no unfriendly relations are presumed to enter to bias the course of procedure. The blue-penciled matter is as follows, and may be compared with the substitute just cited:

PRACTICAL SUGGESTIONS SPRINGING FROM THESE ANALYSES

Final conclusions can, of course, only be reached after the most complete investigation possible, but meanwhile it is important to make all practical advances in the improvement of conditions on which so many lives depend, and every suggestion springing from the investigation is likely to have some value, both in mine control, and in further investigation. To this end, the suggestions of the foregoing observations in the mines, and in the laboratory, will be frankly stated, subject to modifications as further investigation and practical experience require; particularly as these observations and analyses give rise to a very definite suggestion as to a possible mode of reducing the liability of dusts to explode. This suggestion grows out of the striking difference which the analyses disclose between the charred, uncharred, and fresh coal dusts, with regard to the respective percentages of shale in them, particularly as shown on the opposite sides of the props in the Monongah mine. These differences indicate that the proportion of shale present in the dust exerted a marked influence upon the degree of coking, and the extent to which the dusts participated in the explosions. They suggest that the principle which seems to be involved, might be applied to effectually reduce the danger of a general explosion throughout a mine, if not to render such general explosion practically impossible. Even if a local explosion is inevitable at times from the sudden issue of gas, or from some other unavoidable incident, it is important to prevent the general extension of the explosion throughout the mine. In the cases in hand, this seems to have been a most serious phase of the disasters. If a moderate amount of fine shale mixed with the coal dust

may have such a retarding effect upon the charring of the dust, as it appears to have had in the room studied at Monongah, it would seem that, by an addition of sufficient quantities of finely powdered shale, or earth material of similar kind, to the coal dust, we might reasonably expect that the latter would be rendered essentially non-explosive.

. . . .

Whatever may have been the immediate causes which precipitated these terrible disasters, the general, underlying cause of all of them seems to have been an explosive condition of the mine dusts, owing to the drying effect of strong ventilation at this season of the year. The strong ventilating currents were intended to dilute and remove the firedamp before it could accumulate in dangerous quantities, and to furnish good air to the miners. In both of these directions they were effective. But they dried the dusts, and therein seems to lie the source of greatest danger in the bituminous mines of this region. Simple gas explosions without the co-operation of dust could, certainly in the Monongah, and probably also in the Darr and Naomi mines, occur only as very localized explosions of pockets of gas, affecting only a very small portion of the mines. General mine explosions, due to gas alone, would seem impossible with the present ventilating systems of these mines in good working condition. The great extent and destructiveness of these recent explosions seem to have been due almost entirely to the coal dust.

Mutual Relations of Methods of Control

It is obvious that a first condition in the proper control of a coal mine is an effective system of ventilation, for this is the only safe remedy against the dangerous accumulation of methane and other explosive gases which may issue from the coal formation at unexpected times and threaten an explosion. Good ventilation is even more necessary for the health of the miners. It is indispensable. In the mines under investigation it appears to have been wholly adequate, but the investigation seems to show that ventilation itself has its dangers, and that these increase in proportion to the very effectiveness of this necessary measure. During the months in which cold air is forced in large quantities into warm mines, as is inevitable in the on-coming cold season following the summer warmth, the mines, as we have seen, are liable to become excessively dry and subject to dust explosions, even when they are fully protected against all serious gas explosions. Such general dust explosions may start from gas explosions that would, in themselves, be comparatively unimportant, or they may spring from entirely different causes, as defective blasting. The most serious problem, therefore, seems to be the development of practical devices by which the dangers of effective ventilation in the cool season may be reduced to the lowest possible terms. The chief practical suggestion of the foregoing investigation relates to this critical point of forestalling the incidental danger of an adequate system of ventilation which is, in itself, an absolute necessity to good mining conditions.

The chief precaution which has been taken against dust explosions in the past has been to sprinkle the entries with water, but sprinkling the mine with ordinary water is effective only so long as the dust is kept in a moist condition, which is not long in the winter time. This method seems to have been ineffective in these exploded mines because the sprinkling did not reach the various points in the mines until long after the water of the previous wetting had evaporated and the dust become dry. Water, in order to constitute any real safeguard by itself, must be sprayed over all parts of a mine at short intervals. This involves much labor, and, in time, expense. It also has the great disadvantage of weakening the roof in certain mines and increasing the likelihood of rock falls which, after all, cause more fatalities than explosions. Turning exhaust steam into the intake air, while it helps to raise the temperature of the air and supply it with moisture, also favors rock falls, and in addition is said to rot the mine timbers.

A suggestion which has been made is to sprinkle with a solution of calcium chloride instead of pure water. Calcium chloride has such a strong affinity for water that it absorbs moisture rapidly from the air, and a solution of it could never be evaporated dry in ordinary atmospheric air. Dust, wet with a strong solution of calcium chloride should remain damp for a long time, even though the circulating air were in the proper condition to exert a strong drying influence upon the mine. Treated in this way, the dust might be kept so thoroughly dampened that the chances of a dust explosion would be greatly reduced. The expense of using this solution need not be very great, for calcium chloride can be cheaply manufactured. However, with the mine wet with a strong solution of calcium chloride, it is possible that the miners, by constantly coming in contact with it, might suffer both from the rotting of their clothing and possibly an injurious effect upon their health.

Arising from the studies of the dust at Monongah are the suggestions that the explosibility of coal dust may be much reduced by mixing with it finely pulverized shale. One of the most obvious ways to mix this non-combustible matter with the coal dust on the ribs and timbers of a mine is to stir finely ground shale, or similar earthy material, into the water with which the mine is sprinkled. It is clear that means can be devised by which it will be possible to keep shale, mud, or lime constantly stirred up in the water during the operation of sprinkling. When the water dries it must leave behind the mineral matter held in suspension and thus form a coating upon the walls. If this operation be frequently repeated, the amount of non-combustible impurity mixed with, and adherent to, the dust on the ribs must steadily increase and render the coal dust less and less capable of feeding and carrying an explosion flame, so long as the dusts remain mixed.

One of the greatest possible advantages which may be claimed for the use of shale, earth, or lime, in the water, is based upon the property of mud to adhere to that with which it comes in contact, and to hold together, even after

it has become completely dry. By adhering to the particles of fine coal, this dust would be much less readily stirred into the air in everyday mining operations. The mud, clay, shale, or whitewash coating upon the ribs and props must bind the coal dust particles to the coal or timbers with sufficient tenacity to prevent them from being swept up by the ordinary currents of air passing through the entries. Because of greater adhesiveness, mud or soft, clayey shale should be preferable to the more indurated slates, while whitewash has some properties which make it superior to either. Perhaps a mixture of lime and shale, or clay, would prove preferable to either of the constituents used alone.

Since the effects of sprinkling with this shale douche or mixture of earthy material and whitewash last after the water has evaporated, it would not be necessary to sprinkle the entries so often as when water alone is used, for this property of non-combustible shale to diminish the inflammability of the coal dust is not dependent upon the presence of a continuous supply of moisture in the mines. Unlike sprinkling with water alone, if the dust is once made comparatively harmless by the admixture of a very large amount of very fine shale, or similar adhesive mineral matter, it remains so (even though the mine be completely dried out) until an additional amount of coal dust has accumulated, or the dusts in some way become partially separated. Whether the dust be wet or dry becomes less important, though wetness constitutes, of course, an additional safeguard. This manner of treatment implies a certain amount of spraying with water, but a far less amount than the ordinary sprinkling method. Hence the chief dangers of increased rock falls, and other drawbacks of the common water method might be largely escaped.

The treatment of the entry floors is simpler than that of the walls. The pavement may be sprinkled with the same preparation as the ribs and timbers, but it would probably be better to grind the shale to a fine powder outside of the mines, run it underground in the mine cars and spread the dust uniformly over the pavement, throughout the entries. The coal dust on the floor would then either be mixed with, or buried beneath, several times its weight of mineral substance. If sufficient shale be spread along the entries and fairly tight mine cars are used, the shale or earth on the pavement probably would not need to be renewed for a considerable length of time.

Whether shale dust on the entry floors alone, is competent to check a dust explosion once under way, while the fine coal dust, unmixed with shale or whitewash, is present upon the ribs and timbers, can only be told by trial experiment. That an enormous amount of dust and fine particles of coal is swept along the entries during an explosion was strongly brought out by an inspection of the coal ribs in these exploded mines. Very generally throughout these mines, except where the mechanical force of the explosion was greatly reduced, the exposed corners and protuberances of the coal were rounded and often highly polished on exposures facing the source of the explosion, while

nearly always angular and dull on the corresponding exposures facing from the blast. This rounding indicated much abrasion and wear, and resembled somewhat the familiar polishing of bowlders and pebbles by the sand blasts in arid regions. As this smoothing of corners and burnishing of exposed surfaces was all accomplished in the very short length of time which the explosion occupied in traveling through a given section of an entry, the mass of dust and particles of coal carried along by the blast must have been very great. If such a mass of fine, non-combustible shale dust be swept up from the pavement of an entry which has previously been thickly covered with this material, it is possible that the whole explosion might be stopped by this influence alone.

Because the principles of the shale treatment apply to either wet or dry dusts, it would seem that, by this means, the chief danger of over-ventilation during the cold season of the year might be greatly lessened, if not eliminated. With the coal dust thus treated, the gas in the mines could then safely be removed by the vigorous ventilation which is required to remove the firedamp and to supply the miners with fresh air.

The introduction of shale, clay, or whitewash should be free from any injurious effects, either upon the mine or the miners at work. As these substances do not begrime men to anything like the degree that coal dust does, the conditions in the workings should be improved rather than otherwise, from the miners' standpoint. Whitewash, by rapidly absorbing carbon dioxide from the mine air, should have a favorable influence upon the hygienic conditions of a mine. While sprinkling a mine continually with water weakens the roof and increases the number of rock falls, whitewashed walls, by greatly enhancing the illumination of an entry, make it easier to detect dangerous conditions at the roof.

The introduction of pulverized shale, or other earthy material into a mine, thus increasing the quantity of fine dust in the workings, may possibly seem to be increasing one source of danger while reducing another. The experiments of Sir Frederick Abel have shown that certain mixtures of methane and air which passed a naked flame without any symptom of ignition were inflamed when particles of fine, light, non-combustible powder, such as calcined magnesia, were suspended in the gas.[1]

While these gas mixtures were such as could not be exploded by a naked flame they were, nevertheless, not far below the explosive limit. Professor Abel further qualified the statement of his conclusions in this way: "The power of favoring the ignition of mixtures of firedamp and air was not exhibited by some other powders similar in fineness to the latter, but different in structure and density from this and one or two other non-combustible dusts which may be called active; even different samples of magnesia, differing somewhat in likeness from each other, appeared to possess the activity in different degree."

[1] Sir Frederick Abel, *Proc. Roy. Inst.*, X (1882), 88–113.

Only certain dusts, therefore, possess this property which Professor Abel believed to be due to a contact, or catalytic, action upon the gas mixtures, analogous to that manifested by finely divided platinum toward certain gases.

Just how much influence shale dust could exert in this direction has not been determined. It is possible that a mixture of firedamp and air, very close to the lower limit of inflammability, but still not sufficiently rich in methane to be ignited by a flame, might become ignited from the flame when a certain amount of very fine, dry shale dust was stirred into it. But it is probable that only a gas mixture which was very close to the limit of inflammability could become ignited under these conditions. It is also to be remembered that whatever influence of this sort the shale might have, would be possessed, in a far greater degree, by even a very small amount of coal dust in the air. In mines where there is always coal dust present in varying quantities, the possible activity of fine shale in facilitating an explosion should be negligible in comparison to that of the coal dust. Furthermore, the heavier shale, or earthy material, by adhering to the lighter coal dust, tends to keep it out of the air. Finally, the phenomena of typical dust explosions in which the flame, because of the great abundance or excess of combustible matter furnished by the coal dust (even in non-gassy mines), seeks the fresh intake air indicate that these dust explosions are very different from what would be produced by the ignition of mixtures of firedamp and air rendered explosive by the catalytic action of the dust, but, instead, must be largely a matter of the rapid combustion of the readily inflammable hydrocarbons of the dust itself.

Another objection which might be urged is that the shale and coal dusts may become partially separated owing to their difference in specific gravity. Ordinary air currents can pick up light coal dust more easily than denser shale, or clay, particles. As a result, whatever dust might be stirred into the air would be likely to contain a higher proportion of coal than that on the walls or floors. But still there should be much less coal dust in the air, in absolute mass, than if the shale treatment had not been applied, since the mud, because of its adhesive properties, must hold down much fine coal dust which otherwise might easily become floating in the air. However, when an explosion is once started and under headway, it must sweep up nearly all the available dust, coal and shale alike, and hence it would be the character of this mixed dust which would determine the further progress of the explosion.

The foregoing discussion of suggestive preventive measures which were the direct outcome of observational and experimental data have been extended considerably upon theoretical grounds in order to bring out, in a more comprehensive manner, what advantages and disadvantages might be expected to accompany the use of finely pulverized shale, clay, or other earthy material in the mines. The discussion is intended merely to open up, in a preliminary suggestive way, a field for investigation which appears to show some promise of yielding results.

The emasculated substitute for the foregoing discussion that alone found place in *Bulletin 383*, a page and a fraction in extent, seems to have been so far robbed of effective suggestiveness that it did not call forth even a mention by the author of the historical statement of investigations bearing on the use of stone dust as a deterrent in coal dust explosions given the public in *Bulletin 425* recently issued under the same auspices as *Bulletin 383*, though the unemasculated portions of the latter found suitable recognition, as did also and naturally the important advances made in 1908 and 1909 in France, England, and other European countries in this promising line of preventive endeavor, stimulated apparently, in part at least, by the American disasters.

It is of minor consequence that the bureau thus loses a part of its own legitimate prestige in the new movement and falls into line behind rather than abreast of its European coworkers, for such relative position is mainly a matter of national pride, and this is no doubt a form of vanity, however stimulative and wholesome it may be; but it is not permissible to dismiss so lightly the more vital fact that an aid toward that laborious education which is prerequisite to a final practical success was thrown away by cutting out or cutting down to an ineffectual minimum these suggestions that sprang from one of the main lines of approach attempted, even though the suggestions might be thought to overlap ground lying more directly in the path of some other line of approach. The prerequisite educational work is at once scientific, technical, practical, and popular, and will inevitably be slow because of the human inertia to be overcome. It involves the growth of scientific opinion, usually cautious and hesitant, the growth of public opinion, usually inert and sluggish, the working assent of laborers on whom new restraints must be laid, the concurrence of managers on whom new cares are to be thrown, the co-operation of owners on whom new expenses are to be imposed, the enlightenment of legislators of whom new enactments are to be required, and the inspiration of public officials on whom new duties are to be placed. If the psychological moment for such education in any of its phases is at hand, by reason of the shock of appalling

disasters, is it wise to question too closely the nativity or the caste of the schoolmaster? May he not, after all, have rights on other than his native sod and have proper functions outside the caste limits to which certain ancestral conventions might be disposed to confine him?

T. C. C.

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